Appendix A.7.5

BD02 Lackagh Tunnel

A.7.5

Galway City Council

N6 Galway City Ring Road (GCRR)

Lackagh Tunnel - Preliminary Design Report

GCOB-4.04-020-08-001

Issue 3 | 23 October 2017

Job number 233985

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1 Introduction

1.1 Overview

Galway County Council, Galway City Council, Transport Infrastructure Ireland (TII) (formerly NRA)[1] and the National Transport Authority are collaborating to develop a solution to the existing transportation issues in Galway City and its environs. The solution will include a smart mobility component, public transport component and a road component. The N6 Galway City Ring Road (N6 GCRR) is the road component.

As part of the N6 GCRR there are a number of structures envisaged. This report presents the preliminary design of the Lackagh Tunnel (Structure S11/01) in accordance with the guidelines detailed within TII DN-STR-03001 (formally BD02). The Lackagh Tunnel is necessary so as to preserve the area of Limestone pavement within the candidate Special Area of Conservation (cSAC) under which it tunnels.

1.2 Project background information

The N6 Galway City Outer Bypass, an earlier scheme, was previously developed and submitted to An Bord Pleanála (ABP) for approval on 1 December 2006. A brief summary of its history is outlined below.

On 28 November 2008, ABP delivered its decision in respect of the 2006 GCOB. ABP considered that the need for an outer bypass of Galway City connecting the existing N6 on the east to the R336 Coast Road on the west as an essential part of the strategic transport network of the Galway area had been established.

ABP granted approval for the eastern part of the scheme, the section from the N59 Moycullen Road east to the existing N6, inclusive of both junctions at the N59 Moycullen Road and the existing N6. In its decision, ABP noted its consideration of all data presented and granted approval as it considered that the part of the road development being approved would be an appropriate solution to the identified traffic needs of the city and surrounding area. ABP noted that there would be a localised severe impact on the Lough Corrib candidate Special Area of Conservation (cSAC) [2].

However, ABP was not satisfied with the western section of scheme between the N59 Moycullen Road and R336 Coast Road which passed through Tonabrocky Bog. Tonabrocky Bog is:

- part of the Moycullen Bogs Natural Heritage Area (NHA)

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[1] The Minister for Transport, Tourism and Sport signed the order for the merger of the National Roads Authority (NRA) with the Railway Procurement Agency (RPA) to establish a single new entity called Transport Infrastructure Ireland (TII). The National Roads Authority is known as Transport Infrastructure Ireland (TII) since 1 August 2015.

[2] Reference ABP decision 07.ER.2056

- an active Blanket bog listed as an priority habitat in Annex I of the EU Habitats Directive
- the site of a population of Slender cotton grass which is a legally protected and vulnerable species

ABP refused permission for the western section of the scheme between the N59 Moycullen Road and R336 Coast Road on the basis that this part of the road development would not be in accordance with the preservation of the Tonabrocky Bog habitat given the potential for significant adverse effects on the environment and that less damaging alternatives may be available[3].

An application was made by a third party to the High Court seeking leave to issue judicial review proceedings against the ABP decision which granted approval of the eastern section of the 2006 GCOB under Article 6(3) of the Habitats Directive (92/43/EEC), as amended. The basis for the request for a review was that ABP had erred in its interpretation of Article 6 of the Habitats Directive (92/43/EEC), as amended, in arriving at the conclusion that the effect of the 2006 GCOB road scheme on the Lough Corrib cSAC designated site would not constitute an adverse effect on the integrity of the site.

The High Court undertook a judicial review of the ABP decision. The High Court decision of 9 October 2009 upheld ABPs decision to approve the eastern part of the scheme. On 6 November 2009, the third party was granted leave to appeal to the Supreme Court against the High Court decision of 9 October 2009. The Supreme Court sought the opinion of the Court of Justice of the European Union (CJEU) on an interpretation of the Habitats Directive.

The opinion of the CJEU was delivered on the 11 April 2013 (Case C-258/11). The opinion concluded on two significant points:

- The 2006 GCOB would have an adverse effect on the integrity of the Lough Corrib cSAC due to the removal of 1.47ha of Limestone pavement (a habitat type for which the cSAC was selected)
- Given that the 2006 GCOB would have an adverse effect on the integrity of the cSAC, the proposed scheme could not be authorised under Article 6(3) of the Habitats Directive. It could only be authorised under Article 6(4) of the Habitats Directive

The CJEU opinion (i.e. Case C-258/11) established that the loss of a relatively small area of Priority Annex I habitat, where it is a habitat for which the Lough Corrib cSAC is selected, would adversely affect the integrity of the Lough Corrib cSAC and that the provisions of Article 6(4) must apply in granting consent for the project i.e.

6(4) "If, in spite of a negative assessment of the implications for the site and in the absence of alternative solutions, a plan or project must nevertheless be carried out for imperative reasons of overriding public interest, including those of a social or economic nature, the Member State shall take all compensatory measures necessary to ensure that the overall coherence of Natura 2000 is protected. It shall inform the Commission of the compensatory measures adopted".

Following receipt of the CJEU opinion, the Supreme Court quashed the earlier ABP decision to grant approval of the eastern section of the 2006 GCOB under Article 6(3) of the Habitats Directive, as amended.

As the decision of the Supreme Court was that the original 2006 GCOB scheme could not be granted approval per Article 6(3) of the Habitats Directive, the next recourse to secure planning was to advance the scheme under Article 6(4) of the Habitats Directive. Having reviewed the requirements of Article 6(4), it was decided to reassess the work to date to ensure that all possible alternatives were investigated in advance of proceeding under Article 6(4). Therefore, the process of developing a transportation solution for Galway City and its environs had to recommence from the start at Phase 1, feasibility and concept stage, to ensure that all possible alternatives were fully investigated.

1.3 Previous studies and their recommendations

1.3.1 Route Selection Process

Following on from the initial feasibility studies, a suitable scheme study area was determined. Thereafter, the constraints study and route selection process commenced.

Key constraints were identified and examined. These included:

- The physical form of the city with the limited space available between Lough Corrib and Galway Bay
- Established communities, commercial and educational facilities
- Natura 2000 designated sites and Natural Heritage Areas
- Sites of significant architectural and cultural heritage significance

Taking cognisance of the judgement of the 2006 GCOB scheme, the Lough Corrib candidate Special Area of Conservation (cSAC) and the key constraints including those listed above, route options were developed for further assessment. These options comprised on-line options including an upgrade of existing infrastructure, partial on-line/off-line options and new construction off-line. These options were developed and agreed with TII and refined following public consultation and further studies.

A systematic assessment of these options was undertaken which led to the selection of the Emerging Preferred Route Corridor (EPRC) for the road component and this was published in May 2015. Full details of the route option selection process are outlined in the Route Selection Report for the proposed road development.

Previous studies and documents relevant to this Preliminary Design Report are listed below and discussed in more detail below:

- Galway County Council. Project Brief. Phase 1, Scheme Concept and Feasibility Studies (REF/14/11222, 2 May 2015).

- Galway County Council. Project Brief. Phase 2, Route Selection (REF/14/11222, 6 November 2015).
- GCOB-4.04-009 Route Selection Report, Issue 1, 16/03/2016
- GCTP-4.04.03-20.8.001 Tunnel Options Report, Issue 1, 07/06/2016
- GCTP-4.03_03_4.16 Lackagh Tunnel Geotechnical and Hyrdogeological Assessment (currently draft issue)
- Galway Transport Strategy, An Integrated Transport Management Programme for Galway City and environs, Technical Report, September 2016

2 Site & Function

2.1 Site Location

The mainline of the proposed road development passes through a disused quarry, under a section of Limestone pavement 3km north west of Galway City in Coolagh. The area around the Western Approach and Lackagh Tunnel are part of the Lough Corrib cSAC Annex I habitat. This consists of an area of Limestone pavement adjacent to the approach and directly overlying the proposed tunnel.

For the proposed road development, a Type-1 Single Carriageway is proposed for the section west of Ballymoneen Road Roundabout and a Type-1 Dual Carriageway for the section east of the Ballymoneen Road Roundabout, shown in black in **Figure 2.1** below.

Figure 2.1 Emerging Preferred Route Corridor (EPRC), Lackagh Tunnel Site Location

2.2 Function of the structure and obstacles crossed

The primary function of Lackagh Tunnel and Western Approach is as follows:

- Avoid adverse ecological impacts on the Lough Corrib candidate Special Area of Conservation (cSAC) including Qualifying Interest (QI) priority Annex I habitats (Limestone pavement [*8240] and Calcareous grassland [*6210/6210 between Lackagh Quarry and Menlough.

The proposed road development tunnels beneath the Lough Corrib cSAC and the Western Approach passes between it. The maximum tunnel length is 270m with the Western Approach 330m in length.

The area to the east of the tunnel is located in Lackagh Quarry an inactive quarry. Instability in the rock face is evident predominantly from blast damage during the operation of the quarry.

Groundwater data indicates that there is a groundwater divide between Lackagh Quarry and Coolagh lakes, based on this divide the groundwater at Lackagh Quarry will drain south-eastwards away from Coolagh Lakes and groundwater near Menlough will drain south-westwards towards Coolagh Lakes. In the design this is a key consideration to the maintenance of this groundwater catchment separation.

2.3 Choice of location

An extensive constraints and route selection study was carried out for the proposed road development and its findings are presented in the Route Selection Report (GCOB-4.04-009). As noted the EPRC was identified through a systematic assessment of the various route options with respect to the different constraints. The EPRC was identified to traverse beneath the Lough Corrib cSAC at Menlough. The EPRC was selected with Lackagh Tunnel an integral part of the design.

2.4 Site Description

The proposed cross-section of the carriageway through the tunnel is modified in accordance with TII DN-STR-03015 Design of Road Tunnels (formerly NRA BD78). The minimum geometry of the highway cross-section has been determined in consultation with TII. The main constraint on cross-section is maintaining the visibility envelope and facilitating vertical headroom and space proofing for overhead services. The tunnel is located on a slight horizontal bend, and has a vertical low point located just to the west of it.

2.5 Vertical and horizontal alignments

The tunnel location and vertical and horizontal alignments were selected in order to minimise the potential impact to the Lough Corrib cSAC. At this location there is a relatively narrow crossing of the cSAC, which allows for the tunnel to be significantly shorter than alternative alignments beneath the cSAC. Taking into account the ground conditions, hydrogeology, approach alignments and constructability, this location was determined to be the most suitable.

The alignment, described below from east to west, is located to minimise the impact from the excavation on the cSAC. The horizontal alignment consists of a 2040m radius curve, with normal crossfall, throughout the tunnel and majority of the western approach. It connects to a straight at Ch.10+900 and transitions to a 1440m curve at Ch. 10+780 with 2.5% superelevation.

The vertical alignment through the tunnel and western approach consists of a 0.82% gradient connecting to a sag curve with K value of 50. See **Table 2.1** below. A drawing (GCOB-1700-D-S11-01-001) showing the Lackagh Alignment in plan and profile is provided in Appendix A.

Table 2.1: Vertical and horizontal alignments

Name of Structure	N6 Mainline	
	Vertical Alignment	**Horizontal Alignment**
Lackagh Tunnel	Grade = 0.82%	R =2040m
Western Approach	Grade = 0.82% Sag K Value = 50	R =2040m Straight

2.6 Cross Sectional dimensions

2.6.1 Lackagh Tunnel

The Lackagh tunnel cross section is designed to allow sufficient space for the carriageway width, line of sight, emergency walkway, maintenance walkway, ventilation, lighting, signage and communications. An optimised arched profile is fitted to the design section so that the volume of excavated material is minimised and the structure is efficiently designed

The tunnel cross-section contains two bores, one for eastbound traffic and one westbound traffic, with a clear separation of approximately 10m between bores. Both bores requires a clear horizontal dimension of 10.9m. This is to provide for the stopping sight distances of 215m for 100km/h design speed in accordance with TII DN-GEO-03031 (formally NRA TD 9) as well as providing a minimum verge/walkways of 1200mm to comply with TII DN-STR-03015.

Within the tunnel, the highway alignment provides a separation distance of 10m between adjacent verges of the eastbound and westbound carriageways to facilitate the separation between bores.

Although TII DN-STR-03015 indicates a requirement for emergency stopping lanes, the document also notes that continuous emergency stopping lanes are generally not provided due to the associated high costs. A suitable alternative is to provide widened lane widths of 3.75m which has been adopted in this tunnel design in agreement with TII. This widened lane width, in addition to the hard strip and 1.2m verge, is anticipated to provide sufficient width to temporarily allow traffic pass a stranded vehicle.

The modified Urban Motorway Dual Carriageway cross-section proposed for Lackagh Tunnel is:

Eastbound Carriageway

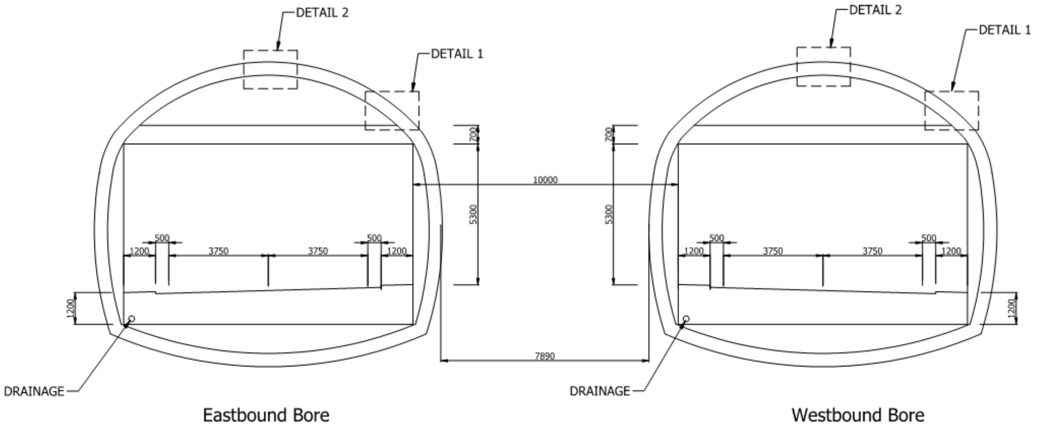
- Left hand verge/emergency walkway	1.2m	
- Left hand Hard Strip	0.5m	
- Carriageway Width	7.5m	(2 x 3.75m lanes)

- Right hand Hard Strip `	0.5m	
- Right hand Verge/emergency walkway	1.2m	

Westbound Carriageway

- Right hand verge/emergency walkway	1.2m	
- Right hand Hard Strip	0.5m	
- Carriageway Width	7.5m	(2 x 3.75m lanes)
- Left Hand Hard Strip	0.5m	
- Left hand Verge/emergency walkway	1.2m	

Figure 2.2 Typical cross section of Lackagh Tunnel in Mined Tunnel



The tunnel carriageway maintains a constant cross-section along the length of the tunnel. The proposed operating headroom within the tunnel above the carriageways is 5.03m and an additional clearance of 0.25m is allowed for beneath the equipment gauge along the entire length of the tunnel giving a total clearance of 5.27m. This additional clearance allows for flapping tarpaulins and other protrusions from trucks.

For consistency with the clearance envelope provided at bridge structures, the minimum clearance of 5.3m will be provided at the carriageway and at the emergency walkways.

A height allowance of 0.7m is provided above the maximum clearance to accommodate the electrical equipment, ITS and tunnel signage. Any fireproof protection measures or construction tolerances, where applicable, will need to be provided outside the envelopes indicated in Figure 2.6 above.

2.6.2 Western Approach

The cross section of the Western Approach is designed to TII DN-GEO-03036. D2UM Standard Urban Motorway. **Figure 2.3** below

Eastbound Carriageway	
- Nearside Verge	3.0m*
- Nearside Hard Shoudler	2.5m**
- Carriageway Width	7m (2 x 3.5m lanes)***
- Offside Hard Strip `	1.0m
Central Reserve	Min 2.60m****
Westbound Carriageway	
- Nearside Verge	3.0m*
- Nearside Hard Shoudler	2.5m**
- Carriageway Width	7m (2 x 3.5m lanes)***
- Offside Hard Strip `	1.0m

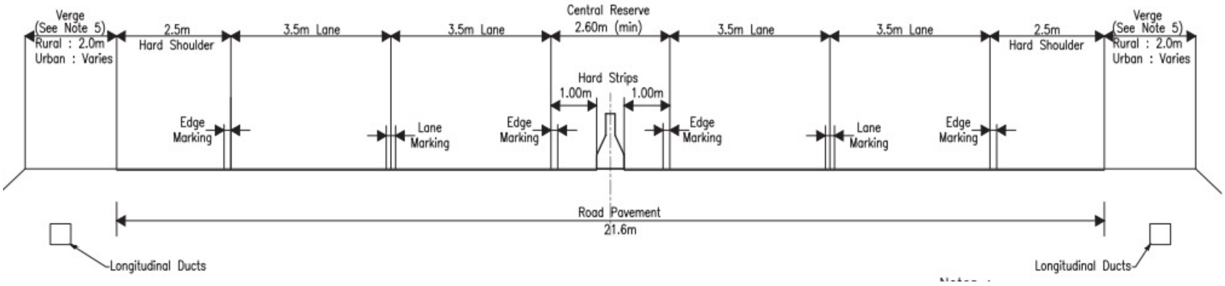
* Verge widths reduce to 1.2m on both approaches to Lackagh Tunnel

**Hard Shoulders reduce to 1m on both approaches to Lackagh Tunnel at a taper rate of 1:60

*** Lane widths transition from 3.5m to 3.75m on both approaches to Lackagh Tunnel at a taper rate of 1:60

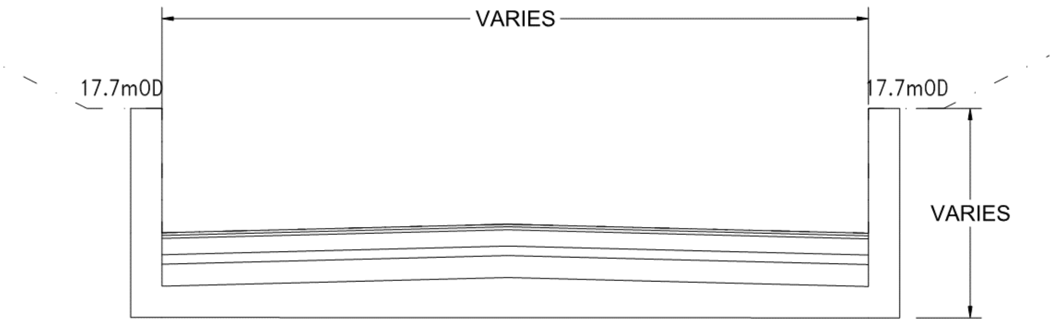
****Median width increases from 2.6m to 10m on both approaches to Lackagh Tunnel at a taper rate of 1:60.

Figure 2.3 Typical cross section of Western Approach



The Western Approach is protected against a high water level of 15.7mOD by the trough structure, which has a minimum height of 17.7 mOD. See **Figure 2.4**

Figure 2.4 Typical cross section of Western Approach Trough Structure



2.7 Existing services

There are no existing services along the proposed alignment.

2.8 Geotechnical Summary

The ground conditions in the area of the Western Approach and Lackagh Tunnel generally consists of instances of deep deposits of glacial till (boulder clay), silt, organic clay, surrounded by shallow bedrock in the form of outcropping limestone pavement in some areas. The following section outlines the geotechnical investigations conducted in the vicinity and also a description of the ground conditions.

The assessment of the geology, ground conditions and geotechnical aspects of the design and construction of the proposed road development at the Western Approach and Lackagh Tunnel is based on the following information:

- The fenceline.
- The vertical and horizontal alignment and
- The available ground investigation information.

The ground conditions along the proposed road development were determined using various sources of information including historic data, photographic evidence, observations from site walkovers, intrusive and non-intrusive site investigations, laboratory testing and on site investigation monitoring.

A conservative geotechnical design approach has been adopted for this assessment. In the event that supplementary information is made available the information will be assessed and the results of the assessment may lead to a more efficient design solution.

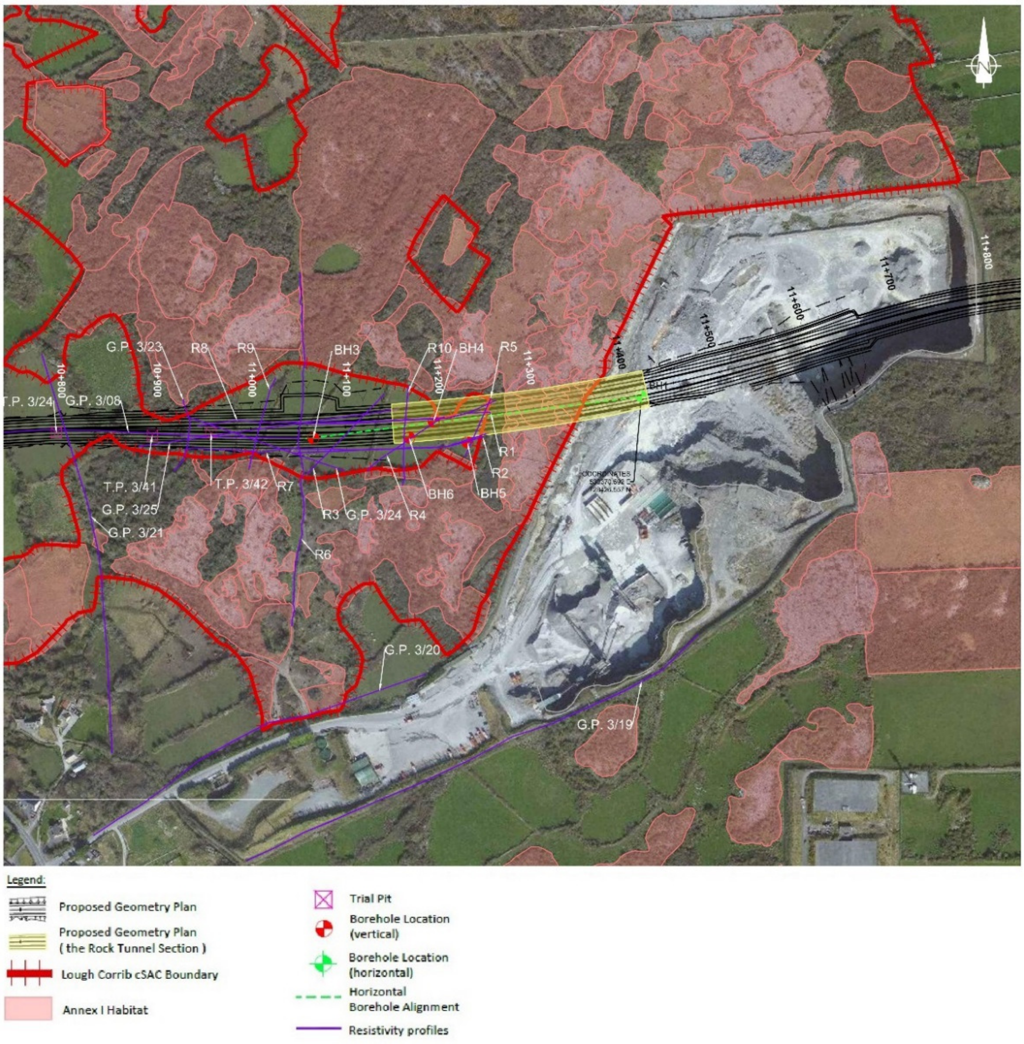
2.8.1 Ground Investigations

Ground investigations were conducted at the western approach and tunnel location as part of the Phase III ground investigation in 2015 and 2016. Two contracts were completed at the tunnel location, which included both intrusive and non-intrusive investigations, which consisted of the following,

- Four vertical rotary coreholes
- One horizontal rotary corehole (at an inclination of ~12° off horizontal)
- Three trial pits
- Microgravity survey consisting of 118 stations
- 16 profiles of Electrical Resistivity Tomography (approximately 3800m of line)
- Six profiles of Seismic Refraction (approximately 1900m of line)

The plan location of the ground investigation undertaken in the area surrounding the tunnel is provided in **Figure 2.5**.

Figure 2.5 Plan location of ground investigation at Tunnel



2.8.2 Ground conditions

The ground conditions are discussed in terms for the Western Approach and Lackagh Tunnel:

- Topography
- Superficial deposits: Overburden details
- Solid Geology: Bedrock details

2.8.2.1 Topography

The western approach is bounded on the north and south by Limestone pavement, where the proposed road development is located in an area of agricultural fields. The existing ground level along the western approach falls from east to west from +30.7 to +17.0 mOD.

The proposed Lackagh Tunnel lies beneath the Limestone pavement within the Lough Corrib cSAC and agricultural fields. The ground levels of the exposed Limestone pavement range from +36.4 to +40.5 mOD along the alignment, falling from east to west. The tunnel extends west beyond the Limestone pavement boundary 120m, overlain by agricultural land where the ground level reduces to +30.7 mOD in the west from +36.4 mOD in the east.

The western quarry wall, at the eastern tunnel portal, comprises of a lower and upper bench, with the lower bench floor at +15 mOD, which rises to +24 mOD at the upper bench with a slope angle ranging from 75 degrees to subvertical in places. The maximum elevation of the quarry wall in this location is +44 mOD.

2.8.2.2 Superficial Deposits

The superficial deposits have been described in terms of two sections to the tunnel as follows,

- Western Approach
- Lackagh Tunnel

Western Approach

Overburden comprises topsoil, glacial till, silt, organic clay, and a transition zone consisting of cobbles and boulders which is likely to be weathered bedrock. Surface geophysics indicate the existence of a large infilled feature on the approach to the western tunnel portal, which was confirmed by BH03.

The glacial till is described as firm to very stiff sandy gravelly clay and occurs from 1.05m and 1.2m, from BH03 and BH06 respectively, to approximately 14m BGL. A layer of very soft silt with faint laminae was encountered from 14m BGL in BH03, for a thickness of 23m. Layers of soft to stiff, occasionally organic clay, were encountered below the silt layer, extending to depths of 80m BGL.

Lackagh Tunnel

Due to the shallow nature of the bedrock, confirmed by outcropping of limestone pavement and available ground investigation information, little to no superficial deposits exist over the footprint of the tunnel.

2.8.2.3 Bedrock Geology

The bedrock is described as strong, thickly bedded to massive, pale grey, fine to medium grained slightly fossiliferous limestone.

Western Approach

A transitional layer of gravels, cobble and boulders, which represents the weathered rock horizon, was encountered, above the slightly weathered to fresh limestone. This transitional zone ranged in thickness from 20 to 25m.

BH03 and BH06 confirmed the geophysics findings, where bedrock was encountered in BH03 at 101.5mbgl (-75.2mOD) and in BH04 at 2.84mbgl (+29.33mOD), and was not confirmed in BH06 as drilling terminated prior to hitting rock. BH03, BH06 and BH04 terminated 109.9m, 45m and 35m below ground level (-83.6, -14.2 and -2.83mOD) respectively.

Geophysical survey lines highlighted high resistivity limestones in the east which give way to a lower resistivity zone to the west. BH06 and BH03, located to the west, penetrated this low resistivity zone proving thick overburden consisting of glacial tills and silts.

Lackagh Tunnel

The Limestone is laterally and stratigraphically homogenous, it is described as pale grey to grey, fine to medium grained, strong to very strong fossiliferous (slightly) weathered (slightly) to fresh massive limestone. The bedrock is described as strong to very strong, thickly bedded, pale grey, fine to medium grained slightly fossiliferous limestone. Argillaceous limestones found in the quarry face were not found during investigation, suggesting that these beds are not present moving west.

Given the nature of the fracturing and the evidence of failures, the angle at which the current rockface stands is too steep, suggesting that this unprotected face, if left in its present state will continue to erode and may potentially impact the overlying Limestone pavement if a deep seated slope failure was to occur.

Karst

A thin 20cm band of laminated mudstone was encountered in BH04, however it is unknown whether this is a continuous layer or a cavity infill. Several cavities were also encountered, some not filled, and some infilled with clay. BH04 and BH05 encountered several cavities, some not filled, and some infilled with clay.

The geophysical survey picked up a zone of low density, low resistivity material beneath the agricultural fields. A large karst feature, up to 109.9m in depth, underlies the agricultural fields in the western approach, with a stepped bedrock profile and deep overburden deposits.

2.9 Hydrogeology

The following section outlines the hydrogeological conditions expected at the Lackagh Tunnel and Western Approach.

These assessments are made based on publically available hydrogeological data as well as site specific ground investigation data undertaken for this project. Groundwater level data has been recorded for the period 2015-2017 for proposed road development. These data include peak water level conditions for the winter of 2015/16 and low winter water level conditions for the winter 2016/17. The water level data is presented in **Table 2.2** and **Figure 2.6** below.

Figure 2.6: Location of groundwater monitoring wells

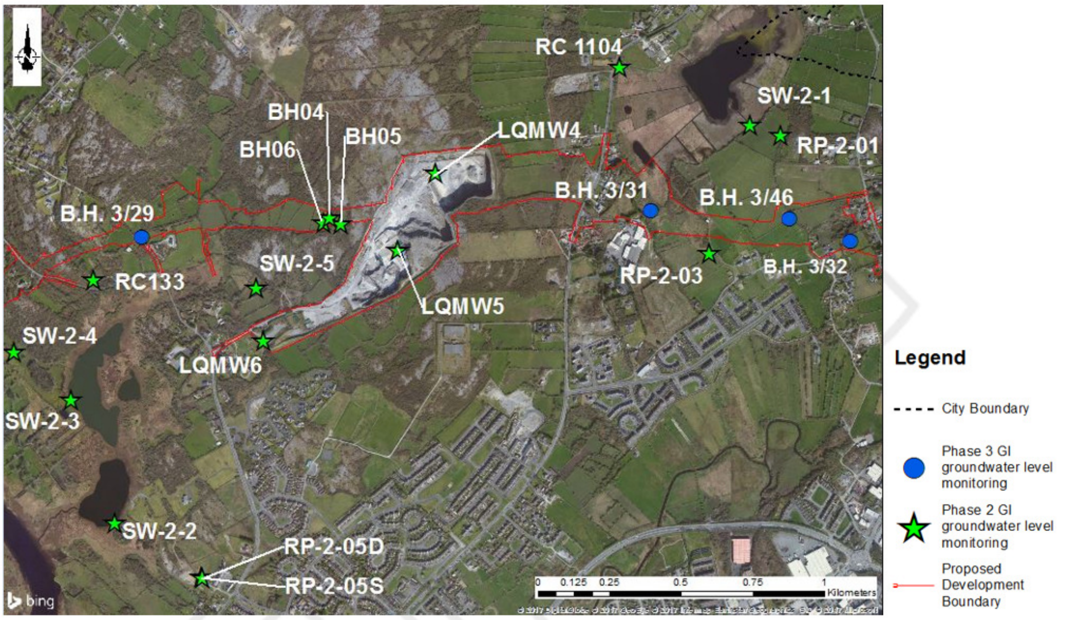


Table 2.2: Minimum and maximum groundwater levels in the vicinity of Lackagh Tunnel.

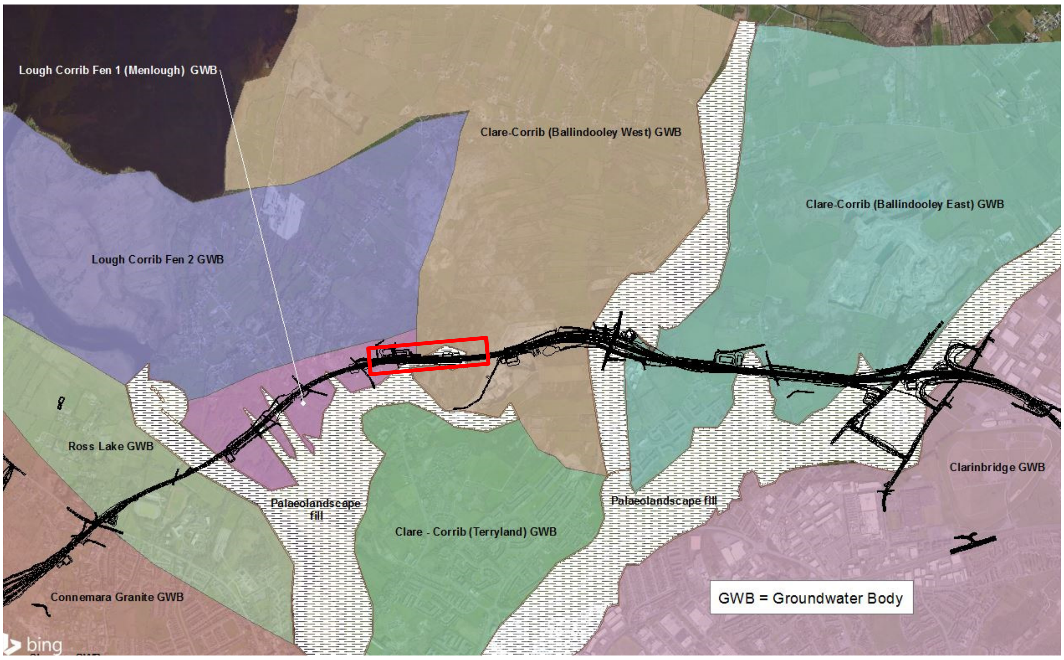
Monitoring Borehole	Source	East ITM	North ITM	Ground Elevation (mOD)	Groundwater		
					Min (mOD)	Max (mOD)	Range (m)
Western Coolagh Spring (K25)	N6 GCRR	529045	727934	5.8	5.7	6.4	0.7
Eastern Coolagh Spring (K45)	N6 GCRR	529900	728162	7.1	7.6	7.7	0.1
LQMW4	Private	530522	728557	16.8	8.8	15.4	6.6
LQMW6	Private	529919	727971	15.4	12.1	13.2	1.1
RC133	2006 GCOB	528670	728095	6.7	5.7	8.2	2.4

Monitoring Borehole	Source	East ITM	North ITM	Ground Elevation (mOD)	Groundwater		
					Min (mOD)	Max (mOD)	Range (m)
RC206	2006 GCOB	528715	727970	9.6	19.3	21.1	1.8
RC 1104	2006 GCOB	531165	728927	9.6	7.2	7.8	0.5
MW 01	2006 GCOB	528670	727956	16.1	10.6	13.9	3.3
MW 02	2006 GCOB	528715	728095	13.4	6.2	7.9	1.8
MW 03	2006 GCOB	528920	727970	6.7	11.2	11.9	0.7
RP-2-01	N6 GCRR	531726	728689	21.4	7.9	10.3	2.4
RP-2-03	N6 GCRR	531478	728278	22.4	4.9	9.1	4.1
RP-2-05D	N6 GCRR	529701	727145	20.00	6.1	7.8	1.6
RP-2-05S	N6 GCRR	529704	727141	20.2	8.9	12.0	3.2
BH04	N6 GCRR	530151	728400	32.2	8.2	15.7	7.5
BH972	2006 GCOB	529462	728292	28.5	7.3	8.2	0.9

Based on the above groundwater level data the Visean Undifferentiated Limestone is divided into a number of groundwater bodies (GWB), with the boundaries between each being groundwater highs. Due to seasonal variations in groundwater levels the extents of the GWB vary across the year but based on the groundwater data collected the lateral shift of the groundwater divide is of the order of 100m.

There are two main groundwater divides within the aquifer along the proposed road development that form three main groundwater bodies, Lough Corrib Fen 1 (Menlough), Clare-Corrib and Clarinbridge (refer to **Figure 2.7**). The naming of the groundwater bodies is based on the naming system initiated by the Geological Survey of Ireland. The Clare-Corrib GWB may be further divided into three sub catchments Ballindooley West, Ballindooley East and Terryland.

Figure 2.7: Groundwater bodies along the proposed road development



The groundwater divide between the Lough Corrib Fen 1 (Menlough) and Clare-Corrib GWB occurs near Menlough, in the townland of Coolough c.200m to the west of Lackagh Quarry. The groundwater divide between the Clare-Corrib and Clarinbridge GWB is located at the Tuam Road.

Lackagh Tunnel and the Western Approach cross the groundwater divide between Lough Corrib Fen 1 (Menlough) and Clare-Corrib (Ballindooley West) Groundwater Bodies (GWB)

2.9.1 Western Approach

As the Western Approach includes both part of the Lough Corrib Fen 1 (Menlough) and Clare-Corrib GWB, the boundary between these ground water bodies lies at the western portal but is likely to vary seasonally and as such is described as being in both the Western Approach and Lackagh Tunnel. As Lough Corrib Fen 1 (Menlough) and Clare-Corrib GWB contribute to European habitats it is important that the road construction retains the groundwater divide between these catchments. The groundwater level in the Western Approach ranges between 8.2m OD (summer) to 15.7m OD (winter).

The peak groundwater levels at the western portal was recorded at a maximum of 15.7m OD (NH04) during the winter of 2015/2016. However, peak groundwater levels in BH972 (450m west of BH04) were recorded with a winter high of 8.2m OD. This data indicates a significantly lower groundwater level to the west of the Western Approach at BH972, which indicates a steep hydraulic gradient or a boundary condition from the groundwater divide westwards in the Lough Corrib Fen 1 (GWB)

As the groundwater levels in BH972 were recorded manually rather than automatically, the more conservative value of 10m OD is used to estimate the winter peak winter peak in BH972 for the winter of 2015/16.

2.9.2 Lackagh Tunnel

The proposed finished road level for the tunnel section ranges from 14.8m OD at the western portal to 17.0m OD at the eastern portal. The peak recorded winter groundwater level is recorded at 15.7m OD in BH04 at the western portal.

The hydrogeological study of Lackagh Quarry area has identified a potential local perched water table and flow path along a clay wayboard in the limestone sequence. The clay wayboard would be intersected by the tunnel and there may be associated inflows along it. These inflows are associated with recharge and in the natural environment would infiltrate down to the regional water table.

2.10 Archaeological Summary

There are no areas of archaeological interest within the influence zone of the Lackagh tunnel and Western Approach.

2.11 Ecology Summary

Lackagh Tunnel traverses beneath the Lough Corrib candidate Special Area of Conservation including Qualifying Interest (QI) priority Annex I habitats (Limestone pavement [*8240] and Calcareous grassland [*6210/6210]. The western approach to Lackagh Tunnel is also surrounded by Annex I habitats, located within the Lough Corrib cSAC and between Coolagh Lakes and Ballindooley Lough. The winter bird surveys detected sightings of various birds in the vicinity. The bat detectors also detected bat activity in the area. Badgers, common frog, smooth newt and common lizard were also recorded in the vicinity. However, none of these are significant constraints to the tunnel construction. Peregrine Falcon are known to roost within the quarry and mitigation measures including a restriction on the timing of when construction activities can commence in the quarry are included as mitigation strategy in the Environmental Impact Statement (EIS) which accompanies the planning application.

2.12 Environmental Summary

The above sections summarise each of the likely environmental impacts. There are no known other environmental constraints that are of such significance in this area as to impose a restriction on the construction of the proposed tunnel. A report on the constructability of the tunnel addresses these issues in greater detail, and a draft of this report is provided in .

2.13 Sustainability

The location and design of the twin mined tunnel at Lackagh Tunnel are chosen to minimise the impact on the environment and the volume of excavated material that will require disposal. Limiting the volume of material reduces the need for multiple truck journeys. Where possible the excavated spoil will be reused on the project.

Reinforced concrete is the primary structural material for the tunnel and the approach structure. Concrete has a high durability performance and requires little maintenance during the design life (120yrs), where the product is appropriately specified and executed. Portland cement replacements such as ground granulated blast-furnace slag (GGBS) will be used where appropriate.

The twin mined tunnel will be naturally ventilated using the piston effect of the vehicles as they drive through the tunnels. Thus the capital, running and maintenance costs of a mechanically ventilated system are obviated. Low energy tunnel systems, such as LED lighting, will be proposed to minimise the energy consumption as well as the required maintenance frequency.

The tunnel control system will be managed from the existing Dublin Port Tunnel control room. Using an existing control room prevents the need for the construction of a new control room.

2.14 Tunnel Details

The tunnel connects the Western Approach to Lackagh Quarry with a box transition structure in the west, two tunnel bores in rock, and a canopy/portal entrance structure in the east. The Western Approach structure has an approximate length of 330m. The transition structure is a box structure of approximately 30m in length but the length may vary depending on the rockhead profile within this transition zone. The eastern canopy /portal entrance structure and the eastbound and westbound bores vary in combined lengths ranging between 240m to 210m.They will be excavated by drill and blast methods and the stability of the bores will be provided with temporary support measures such as:

- Rock dowels installed perpendicular to the tunnel face
- Sprayed concrete
- Forepoling (for areas of weak ground)
- Steel arches (for areas that require stronger support)

Upon completion of the excavation and installation of temporary support the permanent support will be installed in the form of a cast in-situ reinforced concrete lining. A waterproof membrane will be placed between the temporary and permanent structures to ensure the structure is watertight. The invert will also be formed by reinforced concrete and will provide the base for the build-up of the road and drainage systems. Further details of the twin mined tunnels are provided in drawings in Appendix A.

2.15 Accommodation of M&E Services

2.15.1 Ventilation and Mechanical Services

The following aspects of the tunnel design are considered in this section, namely;

- Emergency Points
- Tunnel Ventilation (Natural)
- Fire Fighting Hydrant Main
- Portable First Aid Fire Extinguishers
- Mechanical Services to the Tunnel Services Building and Plant Rooms

2.15.2 Emergency Points

Emergency points shall be provided along the tunnel every 50m. These shall be include the equipment as outlined in BD 78 including firefighting facilities and communication systems.

•

2.15.3 Tunnel Ventilation

The tunnel will be ventilated by natural means using the piston effect of vehicles to induce and push air through the tunnels in the direction of traffic. No mechanically aided systems shall be required. This means that no mechanical smoke control system is proposed and therefore is not subject to agreement with the Tunnel Design and Safety Consultation Group (TDSCG). This is considered typical for a tunnel of 270 m in length.

2.15.4 Tunnel Fire Main

Each tunnel will be provided with a fire main in ductile iron arranged such that they will be joined at each end of the tunnel to form a ring main.

As there is insufficient water supply available from the Local Authority to meet the needs of two hydrants operating simultaneously, a break tank(s) and fire pumps shall be provided and located adjacent to the tunnel service building.

The fire main shall serve hose reel outlets located at 50m intervals. Each hose reel outlet shall be provided with a 30m hose of 19mm minimum internal diameter at 50m intervals to match the location on the emergency points.

Hydrants in accordance with local authority requirements shall be located at regular intervals not exceeding 100m. Within the tunnel, hydrant outlets shall be located approx.750mm above the walkway or verge.

The firefighting crew normally enter the non-fire tunnel where they will prepare and connect to the hydrant main in that tunnel before entering the fire tunnel via the tunnel cross passage doors.

The hydrants shall be used for wash down purposes in the tunnel on an as-needed basis.

2.15.5 Portable first aid fire extinguishers

Two portable fire extinguishers for all types of fires shall be located at each emergency point location. Doors to fire extinguisher and fire hose reel enclosures shall be alarmed to give a signal to the emergency or tunnel control centre when opened.

2.15.6 Electrical Services

The electrical services in the tunnel shall comprise of

- Complete Power Distribution System
- Standby Power System
- Tunnel Lighting
- Emergency Lighting
- Fire Detection
- Cable Containment and Support
- Electrical Infrastructure to Traffic Control, Communications and Information Systems
- Electrical Services to Tunnel Services Buildings and Plant Rooms

2.15.7 Power Distribution

Power distribution in the tunnel will consist of low voltage (LV) distribution boards and cables. Life safety and firefighting services will be designed to operate under expected fire conditions and provided with backup power supplies in case of mains power failure. Back up protection will be provided by UPS and standby generator.

2.15.8 Lighting

Tunnel lighting will be designed to BS 5489: 2016 Part 2 Code of practice for the design of road lighting in tunnels. Lighting will be by suspended high level LED luminaires. Control of lighting in the tunnel will be via dimming and switching for safety and energy efficiency and will take account of night and day time conditions. A standby power supply will operate the tunnel lighting in the case of mains power failure. Standby power for the lighting system will be from the standby generator.

2.15.9 Emergency lighting

Emergency lighting will be provided by high level LED luminaires supported by a static inverter central battery system in the tunnel services building.

2.15.10 Fire Detection

A fire detection system will be provided in the tunnel. This may include the following systems and devices:

- Linear heat detection system which includes sensor cables installed above the travel lanes that automatically activates an alarm at a designated temperature or rate of temperature rise.
- Visual smoke/flame detection system which detects smoke patterns and motion and flame colour and intensity by analysing images from cameras in the tunnel.
- Manual fire alarm points installed at periodic intervals in the tunnel which can be activated by personnel in the tunnel.

The exact system deployed will be based on the parameters of possible fires in the tunnel, environmental conditions in the tunnel and the detection strategy developed as part of detailed design.

2.15.11 Cable Containment and Support

A full cable containment and support system shall be installed in the tunnel including cable ladder, tray, trunking and conduit and suitable support bracketry. Generally, these will be installed at high level in the tunnel.

Electrical Infrastructure to Traffic Control, Communications and Information Systems.

Electrical infrastructure (power, cables and cable containment, etc.) will be provided for the various Traffic Control, Communications and Information Systems as part of the electrical services.

These systems would include CCTV, VMS, EMS, Telephones, Traffic Monitoring, and Radio Broadcast Systems as required.

2.15.12 Distributed Antenna Systems (DAS)

A multi-operator in-tunnel system will be installed to improve mobile coverage. The proposed solution is a BTS or repeater driven distributed antenna system (DAS) designed to enhance three GSM operator’s coverage.

The installed system can be broken down into the following distinct sections;

- MNO donor antenna
- MNO repeater
- Point of interface (POI – multi-operator combiner)
- Fibre optic master unit (OMU)
- Multiband remote unit (OMU)
- RF cabling and splitter system (x2)

- Tunnel coverage antennas (x4)

Where applicable, other radios bands are to be accommodated such as Tetra, FM and maintenance radio.

2.16 Location of the tunnel services, monitoring and maintenance

The tunnel services, monitoring and maintenance building (TSB) shall be located on the south side of the western portal of the tunnel in Lackagh Quarry. The TSB may include office areas, control room, technical equipment room(s) (TER(s)), staff welfare facilities, stores and plant rooms to assist with the monitoring and control of traffic and systems both leading up to and within the tunnel.

The TSB will house operations personal and tunnel plant and equipment. Electrical services will be provided to the TSB including all power distribution, standby generators, lighting, life safety and communications requirements.

Heating, ventilation and air conditioning will be required to the TSB. In particular, the TER(s) containing all of the control and communicating equipment will be provided with duty and standby close control air conditioning systems.

Public health systems to the tunnel service building will include mains, cold and hot water supplies, and foul drainage to all sinks and sanitary ware.

Firefighting equipment to the service building will include portable first aid fire extinguishers. The TER(s) will be fitted with automatic gaseous fire suppression systems to protect the equipment within.

The duty and standby hydrant pumps (if required) for the tunnel hydrant system shall be located in the TSB. The water storage required shall be located externally immediately adjacent to the hydrant pump room.

It is generally anticipated that plant rooms shall be naturally ventilated.

Where temperatures within plant rooms cannot be contained within tenable conditions, wall mounted axial fans will be provided behind louvres to assist natural ventilation air flow rates. Electrical heaters shall be provided to ensure that all plant rooms are maintained above 4°C.

3 Structures and Aesthetics

3.1 General Description

The following structures are covered in this preliminary design report:

- Lackagh Quarry Portal: Located on the eastern side of the Lackagh Tunnel and forms the entrance to the tunnel. It will be designed to the winter high water level to prevent any ingress of flood water into the tunnel. The rock face surrounding the tunnel will be stabilised with a system of steel mesh, rock bolts and sprayed concrete.
- Lackagh Tunnel: Connects Lackagh Quarry to the Western Approach and comprises twin mined tunnels for the eastbound and westbound carriageways. Each bore comprises a 12.5m (circa) wide span tunnel with watertight concrete arch lining with the internal elements (road, walkways, lighting, ventilation etc.) placed within this shell. At the western end of the tunnel, where the depth overburden increases, it is expected that there will be a transition construction from the mined tunnel to the Western Approach structure. This transition structure is likely to consist of a pair of concrete box structure, construction using cut and cover methods. It is likely that some temporary ground retention measures will be necessary to construction this transition structure.
- Western Approach: Connects Lackagh Tunnel to Menlough and is formed from U-shaped trough structures which provide a water cut off and minimise the impact to the Lough Corrib cSAC. The top of retaining walls range from 17.7mOD to 21.7mOD.

Further details of the tunnel portal, the tunnel and western approach structure are provided in drawings in Appendix A.

3.2 Aesthetic Considerations

The visual impact on the overall landscape is the tunnel portals and the western approach cutting. The aesthetic treatment of the entrance and exit portals is important. Both portals are located below existing ground level minimising their visual impact on the surrounding area. The exposed surfaces of the tunnel and the portals will be typically of reinforced concrete construction, with the appropriate detailing in terms of concrete finishes, headwalls and coping elements. Where necessary a canopy structure may be provided at the portal entrances, to ensure the appropriate transition in lighting/shading conditions.

Above eastern tunnel portal a composite support system may be installed locally, where required, to retain the bedrock at this location. This composite structure will comprise of rock bolts, rock dowels, steel mesh and shotcrete.

The western tunnel portal is located at an appropriate distance from the exposed limestone pavement, to permit a sloped embankment above the portal.

At the Western Approach structure, the exposed vertical walls will consist of reinforced concrete. Given the large area of concrete, the use of feature finish is proposed at this location. The ground slopes behind the U-shaped structure will be vegetated where possible.

Further details are provided in drawings within Appendix A. The aesthetic treatment of the portals will require further input from an aesthetic advisor.

3.3 Proposal for Structure

The proposed structure at Lackagh (S11-01) consists of a tunnel with a maximum length of 270m and 330m approach structure, as described in Section 2.14.

3.3.1 Proposed Category

The Lackagh Tunnel and Western Approach are proposed to be Category 3 in accordance with DN-STR-03001 (TII BD2/09).

3.3.2 Span Arrangements

The internal span of the mined tunnels is expected to be approximately 12.5m and at a maximum of 240m long, transitioning from rock through an approximately 30m long transition box structure. The transition box structure will have internal spans of approximately 10.9m. The trough structure in the western approach will vary in width up to 38m and 330m in length at varying depths.

3.3.3 Approaches including run-on arrangements

On the approaches to the tunnel from the western side, the ground conditions change from glacial till to rock. Due to the different vertical stiffness of the ground at formation level at this location, there is potential for differential settlement between the approach structure and the tunnel structure. In order to prevent these differential movements a zone of ground improvement works is expected to provide a suitable transition length to accommodate the potential settlement, inconjuction with appropriate detailing for movement at the interface between the adjacent structures.

Further details are provided in drawings in Appendix A.

3.3.4 Substructure

The founding strata for Lackagh Tunnel will be entirely founded on limestone bedrock which provides an extremely stiff and stable founding material. The founding strata for the transition structure will vary between limestone bedrock to cobbles and boulders to stiff glacial till. The founding strata for the western approach varies from an east to west direction between stiff glacial till becoming soft organic clay and transitioning again into glacial till to cobbles and boulders to limestone bedrock. Please refer to Section 3.3.5 for further information on the foundation required due to the variation in geology.

3.3.5 Foundation Type

Along the Western Approach Structure, the balance between the weight of the structure, the buoyancy due to the high ground water table and the movements associated with the seasonal variation in water levels means that measures to prevent uplift will be required. It is envisaged that the use of ballast, rock anchors and tension piles are potential foundation options for the approach structure.

Within the Lackagh Tunnel the lining transfers the loads to the tunnel invert and into the bedrock. The invert effectively becomes the foundation of the tunnel. The thickness of the lining and bearing capacity of the bedrock is checked to ensure both the structure and ground . Where local weak zones or karst features are encountered in the founding zone then they will be excavated and filled with mass concrete in order to provide the required strength for the foundation.

3.3.6 Superstructure

At the Western Approach Structure a reinforced concrete trough structure will be constructed, which will provide a cut off to the high water level and will minimise impact to the Lough Corrib cSAC in terms of spatial requirements. The walls will consist of cast initu walls, with secant piled walls likely at some locations.

The proposed superstructure in the mined Lackagh Tunnel will be formed using shotcrete and cast in-situ reinforced concrete liners.

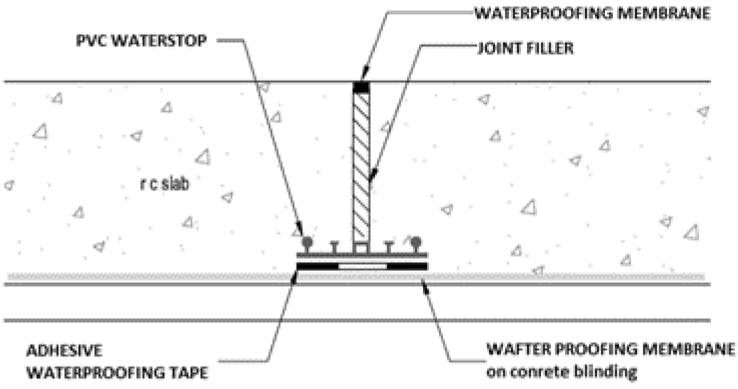
The transition structure at the western portal will consist of a cast insitu concrete box structure.

3.3.7 Articulation arrangements, joints and bearings

It is anticipated that the approach structures will contain movement joints, but that there will be no movement joints in the mined tunnel. There are no bearings or expansion joints proposed at this structure.

A typical arrangement for the movement joints is shown in Figure 3.1 below

Figure 3.1: Movement joint detail in approach structure (typical)



Refer to Section 3.8 for further details.

3.3.8 Parapet

Refer to Section 4.3 for further details.

3.3.9 Inspection and Maintenance

During the life of the tunnel, a regular inspection and maintenance regime should be implemented. Regular visual inspection of the tunnel lining should give early indications of any problems such as water ingress, cracking and corrosion of steel.

The headwalls and wing walls will be inspected from the mainline. The underside of the roof and the exposed portions of the walls can be inspected from beneath.

Waterproofing systems, joints, parapets etc. shall be designed for Working Life Category 2 (replaceable structural parts, up to 50 years design working life).

All other elements of the structure shall be designed for Working Life Category 5 (⩾120 years design working life).

A Maintenance & Operations Strategy will be produced, and during the design phase this strategy will be developed in a Maintenance & Operations Manual for the Safety File.

3.4 Description of tunnel traffic and road geometry

The following table indicates the predicted traffic volumes in the Lackagh Tunnel as extracted from the TII Central Growth AADT figures for opening year, 2024 and design year, 2039. Figures shown indicate medium and high growth scenarios.

Table 3.1: Lackagh Tunnel AADT and HGV%

Growth Scenarios	AADT	HGV
TII Medium Growth – 2024	31,409	4%
TII Medium Growth – 2039	36,353	5%
TII High Growth – 2024	31,608	4%
TII High Growth - 2039	37,190	4%

Refer to Section 2.5 and Section 2.6 for details regarding the road geometry.

3.5 Accommodation of M&E services

Refer to Section 2.15.

3.6 Emergency communication, escape facilities, fire points, cross passages

Refer to Section 2.15 and 3.13.

3.7 Drainage Details

A sealed drainage system will be provided within Lackagh Tunnel. Inflow and discharge rates are calculated based on the influences of groundwater, rainfall, tunnel wall washing and firefighting purposes as outlined in DN-STR-03015 (BD78/99).

There will be one drainage sump location, situated north of the carriageway and outside the western tunnel portal, as the vertical curvature falls along the tunnel alignment from east to west. The outfall from the sump will be pumped via a rising main through the tunnel to the existing foul rising main sewer on the N84 Headford Road that serves the Carrowbrowne landfill. Approval in principle has been obtained from Irish Water for this foul connection which accounts for the proposed discharge rate and volume. See drawing no. GCOB-1700-D-S11-01-027 in Appendix A for the proposed sump location.

3.7.1 Ground water seepage

Preliminary investigation of the groundwater table indicates that part of the tunnel lies below the regional water table. The tunnel will be designed to be fully sealed up to the extreme winter ground water level. The drainage system will be designed to cater for expected leakage rates for a sealed tunnel as per DN-STR-03015 (BD78/99).

3.7.2 Rainfall

As the low point of the vertical alignment is located west of the Lackagh Tunnel and the highpoint is located to the east of Lackagh Tunnel, the direction of the rainfall flow on the carriageway is from east to west, with the rainfall flowing downhill away from the tunnel portal on the western approach and toward the tunnel on the eastern approach. Separate sealed carriageway drainage networks are provided to intercept the storm water and to prevent it from entering the tunnel, hence there is no external rainfall catchment contributing to the tunnel drainage system.

Drips from vehicle wheels are expected, but did not form part of the capacity assessment for the tunnel drainage network.

3.7.3 Tunnel wall washing

It is expected that tunnel wall washing will be carried out quarterly, therefore the volume and flow rates from same will be intermittent. All wash down from the tunnel will be collected in the drainage sump and pumped to the existing Carrowbrowne rising main. No water arising from wash down operations is permitted to discharge to the groundwater system or any storm sewer. The quantity of water from wall washing are calculated as per DN-STR-03015 (BD78/99).

3.7.4 Firefighting and wash down following spillages

An allowance of two hydrants has been provided to be used by the Fire Services during firefighting incidents for a 1 hour duration. The duration of firefighting is to be confirmed with the Local Authority Fire Services. The proposed potable water connection will be to the 150mm diameter watermain on Coolough Road, approval in principle has been obtained from Irish Water for this connection which accounts for the proposed rate and volume. Flows and volumes for firefighting are calculated as per DN-STR-03015 (BD78/99). The firefighting flows will be contained in the firefighting/wash down buffer tank before being pumped to the existing Carrowbrowne rising main.

In the event of both a fire and the spillage of dangerous goods within the tunnel, the wash down will be contained within the firefighting/wash down buffer tank where it can be excavated manually as required.

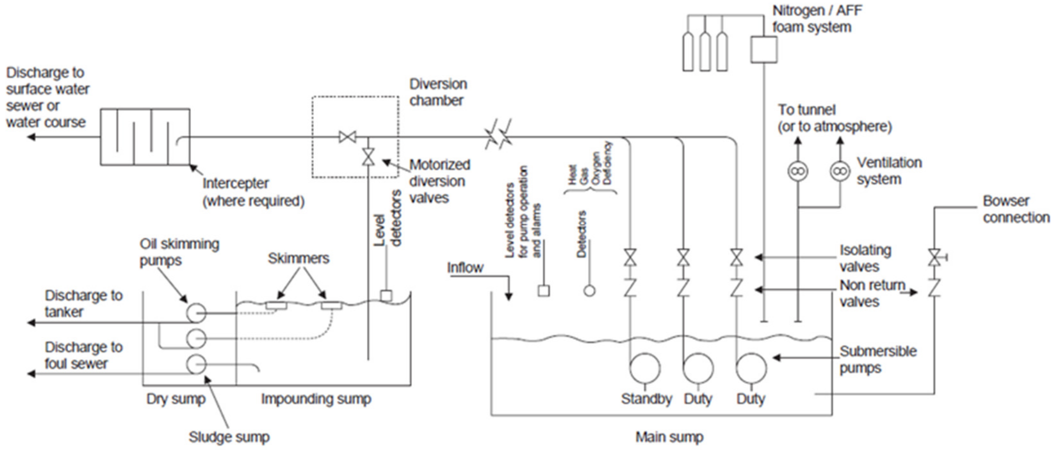
3.7.5 Accidental spillage

A 25m^3 impounding drainage sump, in accordance with HD33/15, will cater for a spillage of hazardous liquid from one road tanker. This will be located adjacent to the pump sump and station. The impounding drainage sump can be isolated and evacuated manually to a bowser vehicle for appropriate disposal independently of the main pumps or discharge pipework. An oil and petrol interceptor will be provided prior to discharge to the existing Carrowbrowne rising main in accordance with DN-STR-03015 (BD78/99).

3.7.6 Pump station

All pump station M&E will be designed in accordance with best practice guidelines, taking into consideration fire precautions. The figure below is an extract from DN-STR-03015 (BD78/99) showing a typical pumped drainage system arrangement within a tunnel environment.

Figure 3.2: Typical pumped drainage system



3.7.7 Fire main burst

In the event that a fire main is damaged and bursts, the excess water will be collected by the drainage system, transferred to the drainage sump where it will be retained in the firefighting/wash down buffer tank, before being pumped to the existing Carrowbrowne rising main. Due to the large quantity of water which could arise in such an incident the duty of the pumping system will include for the potential outflow from a broken pipe as per BD78/99 requirements.

3.8 Articulation arrangements

The water tightness of the movement joints is ensured by a single, high quality rubber metal waterstop. In order to ensure the waterstop works properly injection tubes are provided at the end of the metal straps. In addition movement joints will be required at the connection to the wingwalls.

Continuous reinforcement will be provided across the construction joints and no movements are foreseen. Where appropriate, waterstops can be provided at construction joints.

3.9 Environmental conditions within the tunnel service, monitoring and maintenance building

Based on the following external design conditions the heating ventilation and air conditioning (HVAC) systems for the TSB shall be designed to achieve the following design internal conditions:

Table 3.2: Design internal conditions

	Summer	Winter
Design External Condition	26OC db, 19OC wb	-3OC db, -3OC wb
Design Internal Conditions		
Offices, reception	23+/-2OC wb	21+/-2OC wb
TER's	22+/-2OC wb	22+/-2OC wb
Plantrooms	<30 OC	>4 OC

3.10 Ventilation in the TSB

It is anticipated that the office and reception areas shall be naturally ventilated by means of openable windows.

The TER's will be provided with mechanical ventilation to slightly pressurise the room.

The plantrooms shall be naturally ventilated by means of louvres located in walls or doors.

A dedicated toilet extract system shall be provided to all washroom and changing facilities.

3.10.1 Justification

The design of HVAC systems shall be in accordance with CIBSE recommendations.

3.10.2 Pollution and vehicle emission

If deemed required based on estimated pollution levels in the vicinity of the tunnel, the supply air systems to the TSB facility shall be provided with charcoal filters to deal with emissions from vehicles.

3.10.3 Fresh air requirements

Fresh air requirements shall be in line with the recommendations for CIBSE. In general where mechanical ventilation is provided it shall be sized to deliver a minimum of 10l/s per person based on normal expected occupancy.

3.10.4 Monitoring and control

The HVAC systems shall be provided with a digital control system to allow users control temperature set points and plant running times within set limits. Frost protection will be provided to automatically start up HVAC to maintain minimum internal temperatures.

3.11 M&E elements of drainage in the TSB

Foul drainage from sinks and sanitary ware in the building shall be collected by means of a single pipe ventilated system. The foul drainage shall discharge by gravity to the private foul sewer in the vicinity of the proposed new building.

Storm water from roof and canopy areas shall be collected and shall discharge by gravity to the local authority main in the vicinity of the proposed new building.

3.11.1 Design criteria

Above ground foul drainage and storm water systems shall be in accordance with IS EN 12056. All design requirements from Irish Regulations Part H will be incorporated.

3.11.2 Volumes to be handled

The volumes of foul water from the proposed service building are domestic in nature. Normal occupancy levels are expected with an assumed usage of 60 litres per person per day.

The storm water system for the roof of building will be designed for a 1 in 100 year event.

3.11.3 Pumping equipment

It is anticipated that drainage from the service building shall be by gravity and no pumping equipment will be needed

3.12 Electrical services in the TSB

3.12.1 Electrical supply

It is expected that ESB Networks (ESBN) will provide an MV supply to the building. This will be rated at 10kV initially with a possible future increase to 20kV.

An ESBN MV substation will be required in the building

3.12.2 Electrical distribution system

The electrical distribution system will be configured with two independent, diverse, active distribution paths (denoted A & B) serving equipment in the TSB and the tunnel. Both A & B systems will be fully live and operational at all times.

Distribution will be via distribution boards and cables.

3.12.3 MV switchgear

An incoming MV switchboard will be provided.

MV switchgear will be free-standing, air insulated, metal-clad type complying with EN 62271-200. MV breakers will be vacuum insulated and withdrawable.

3.12.4 Transformers

Two MV/LV step-down transformers will be provided. They will be dry type cast resin and will be low loss with an efficiency class of AoAk in accordance with EN 50541.

They will have dual 20kV and 10kV primary windings and 400V secondary winding.

Both will be rated to be capable of supporting the full load of the facility.

3.12.5 LV generator

A standby diesel generator will be provided. Output voltage will be 400V.

The generator will be rated to be capable of supporting the full load of the TSB and tunnel without load shedding.

Generator power rating category will be Prime Power i.e. capable of delivering continuous power while supplying a variable electrical load for an unlimited number of hours per year. It will comply with transient response performance class G2 as defined in ISO 8528-1-7.

The generator will have an integral base fuel tank with capacity to allow the generator to run for 12 hours on full load. A separate double skin bulk fuel tank will be installed in an external bunded area with capacity to allow the generator to run at full load for 48 hours. A fuel washing system will be installed.

A loadbank will be provided to allow the generator to be fully load tested regularly.

There will also be a facility to connect a generator to the switchgear via power lock connectors. This will allow a temporary mobile generator to be connected if the generator is out of operation for a period.

Generator operation will be controlled automatically from the Power Management System.

3.12.6 Uninterruptible Power Supply (UPS)

Two static UPSs and batteries will be provided to give A&B UPS supplies (2N redundancy).

UPS will be high efficiency with multiple operating modes (VFI, VI, VFD) including energy saving modes.

Both will be rated to be capable of supporting all essential services in the TER, control room and tunnel.

The UPSs will comply with I.S. EN 62040 'Uninterruptible Power Systems (UPS)'.

3.12.7 LV switchgear

Two main switchboards will be provided for the A and B supplies.

Automatic Power Factor Correction (PFC) equipment will be connected to the switchboards.

All Switchboards and Distribution Boards will comply with I.S. EN 61439 'Low Voltage Switchgear and Controlgear Assemblies'.

3.12.8 Power Management System (PMS)

A Power Management System will be provided to automatically control the switching between mains incomer, generator and UPSs.

The control system will be able to synchronise the generators to the electrical supply for testing and no-break return to mains.

3.12.9 Power monitoring system

Power meters will be installed on all supplies from the main switchboards and in individual sections of distribution boards.

A power monitoring package will monitor, record, analyse and present power data from the meters in spreadsheet and graphical form.

This will form part of the Building Management System (BMS).

3.12.10 Cable support & containment

A complete cable support and containment system will be installed using galvanised steel cable ladder, tray, basket, trunking, conduit and support steelwork.

ICT cabling distribution in the TER will be installed overhead (basket for copper and plastic trunking for fibre).

3.12.11 Small power distribution

Socket outlets will be provided as required for the operation and maintenance of the facility.

Dual redundant UPS supported A & B power supplies will be provided to racks in the TER via plug-in tap-offs on overhead A&B busways fed from dedicated Power Distribution Units (PDUs) in the TER.

Dual redundant UPS supported A & B power supplies will be provided to consoles in the control room.

3.12.12 Electric car charging

Electric car charging stations will not be provided.

Underground ducting will be installed from the LV Switchroom to the car park to allow for future installation of stations.

3.12.13 Interior lighting

LED luminaires will be used throughout. Generally, this will include downlights in circulation areas and toilets, recessed linear fittings in rooms and office spaces and surface mounted linear fittings in plantrooms.

Lux levels will generally be in accordance with CIBSE Code for Lighting 2012.

3.12.14 External lighting

External lighting will be provided by wall and column mounted LED fittings. All external luminaires will be vandal proof fittings.

Lux levels will generally be in accordance with CIBSE Code for Lighting 2012.

3.12.15 Lighting controls

A Lighting Control System (LCS) will be provided with a graphical front end on an LCS server.

Automatic (presence/absence detectors and light level sensors) and manual (switches) lighting control will be provided throughout.

External lighting will be controlled by external photocells and an on-off-auto switch in the distribution board.

3.12.16 Emergency lighting

Emergency lighting shall be provided by separate dedicated non-maintained LED luminaires supported by a 3 hour Central Battery System (CBS).

Maintained self-illuminated exit signs will be provided on escape routes with non-maintained emergency bulkheads over external doors.

The emergency lighting installation will comply fully with I.S. 3217 and the CBS with I.S. EN 50171 ‘Central Power Supply Systems’.

3.12.17 Fire Detection & Alarm System (FDAS)

An analogue, fully addressable, automatic Fire Detection & Alarm System will be provided in the building. It will be Category L1 to cover all areas.

A VESDA (very early warning aspirating smoke detection) system will be provided in the TER and its underfloor void.

The system will comply with I.S. 3218 ‘Fire Detection and Alarm Systems for Buildings - System Design, Installation, Servicing and Maintenance’. All components will comply with I.S. EN 54 ‘Fire Detection and Fire Alarm Systems’

3.12.18 Fire suppression

A Fixed Gaseous Fire Extinguishing System will be provided in the TER.

The extinguishing agent shall work by using a heat absorption/chemical reaction process. It will be stored as a fluid and change to gas when released into the room. The storage cylinders will be stored in an adjacent separate room.

The system will comply with I.S. EN 15004 “Fixed firefighting systems - Gas extinguishing systems” and ISO 14520 “Gaseous fire-extinguishing systems”.

3.12.19 Information & Communication Technology (ICT)

All ICT cabinets will be located in the TER.

All ICT outlets in the building will be wired to the racks in the TER using horizontal Cat 6A cabling.

A wireless network (WLAN) will be provided within the building.

3.12.20 Distributed Antenna System (DAS)

A full, multi-operator, repeater fed, active, fibre optic distribution system will be installed to allow mobile phone coverage in the tunnel.

A Point of Interface (POI) will be provided in a DAS room in the TSB to allow multiple GSM operators to connect their networks to the DAS which will combine and distribute the signals through antennas in the tunnel bores.

3.12.21 Intruder Detection & Alarm System (IDAS)

An Intruder Detection and Alarm System will be provided to prevent unauthorised access to the compound and building.

The system shall comply with I.S. EN 50131 ‘Alarm Systems – Intrusion Systems’.

3.12.22 CCTV

CCTV surveillance will be provided at the main gate, car park, building perimeter, entrances/exits, reception, lobbies and TER.

The CCTV system will be an IP PoE system generally comprising of internal and external cameras, colour display monitors, network recorder and associated equipment.

Images will be recorded on a local Network Video Recorder (NVR).

The system will comply with I.S. EN 50132 ‘Alarm Systems – CCTV Surveillance Systems for use in Security Applications’.

3.12.23 Access Control System (ACS)

Access control will be provided at access gates, entrances/exits, secure rooms and plantrooms to regulate access to secured areas of the facility.

Internally, proximity card readers will be used. External card readers will include a keypad for additional security (requires card and PIN for entry).

The system shall comply with I.S. EN 50133 ‘Alarm Systems – Access Control Systems for use in Security Applications’.

3.12.24 Earthing and bonding

A complete earthing and bonding system will be provided in full compliance with all requirements of the relevant standards and regulations.

The Main Earthing Terminal (MET) for the installation will be an earth bar in the LV Switchroom and the earthing and bonding system will be connected to that point.

A separate functional/clean earth will be provided. This will be connected directly to the MET only. A functional earth bar will be provided in the TER to connect all clean earths in the room.

3.12.25 Lighting Protection System (LPS)

A Lightning Protection System (LPS) will be provided on the building. The Lightning Protection Level (LPL) class will be based on a specific risk assessment carried out for the facility.

The LPS will be fully coordinated with the surge protection system.

The system will generally comprise roof level air termination network, dedicated down copper tape conductors, earth electrodes, test points and bonding of all extraneous metalwork.

The system and equipment shall comply with I.S. EN 62305 ‘Protection Against Lightning’ and I.S. EN 50164 ‘Lightning Protection Components (LPC)’

3.12.26 Surge protection

Electrical and electronic systems within the building will be protected from any damage which may be caused by lightning electromagnetic impulse (LEMP) by designing, installing and testing a LEMP Protection Measures System (LPMS).

Service entry Surge Protection Devices (SPDs) and co-ordinated SPDs will form an integral part of the installation in keeping with the determined LPL protection level from the lightning protection system risk assessment.

All cables including incoming data links and comms lines entering the building will be surge protected with service entry SPDs.

The system and components shall comply with I.S. EN 62305-4 'Protection against lightning. Electrical and electronic systems within structures' and I.S. EN 61643 'Low Voltage Surge Protection Devices'.

3.13 Tunnel fire safety

3.13.1 Basis of design

It is noted that the EU Directive 2004/54/EC (transposed into Irish Law by SI 213 of 2006) does not apply to this tunnel as it is less than 500 m.

The UK guidance document BD 78/99 Design of Road Tunnels has been used as the main fire engineering guidance document with due cognisance of the risk based criteria outlined in the EU Directive. This guidance document is relevant to all tunnels > 150 m in length. The Lackagh Tunnel has a maximum length of approximately 270 m in length. This document is therefore considered appropriate.

3.13.2 Fire risk

The Lackagh tunnel is considered to be of relatively low risk for the following reasons:

- It is a relatively short tunnel and therefore:
    - The risk of a fire in the tunnel is lower.
    - Emergency services will be able to access the tunnel relatively easily.
    - Smoke will be able to escape from the tunnel relatively easily via the portals.
- Should a tunnel bore have to close due to planned maintenance, breakdown, etc. there is no need to put a contra-flow in operation as alternative traffic routes are available and could be used. This means that in all cases, traffic will be moving in the same direction.
- The Heavy Goods Vehicles (HGV) usage of the tunnels is relatively low (Galway Racecourse Tunnel is 4% and Lackagh Tunnel is 4%), the chance of a HGV fire within the tunnels is therefore low.

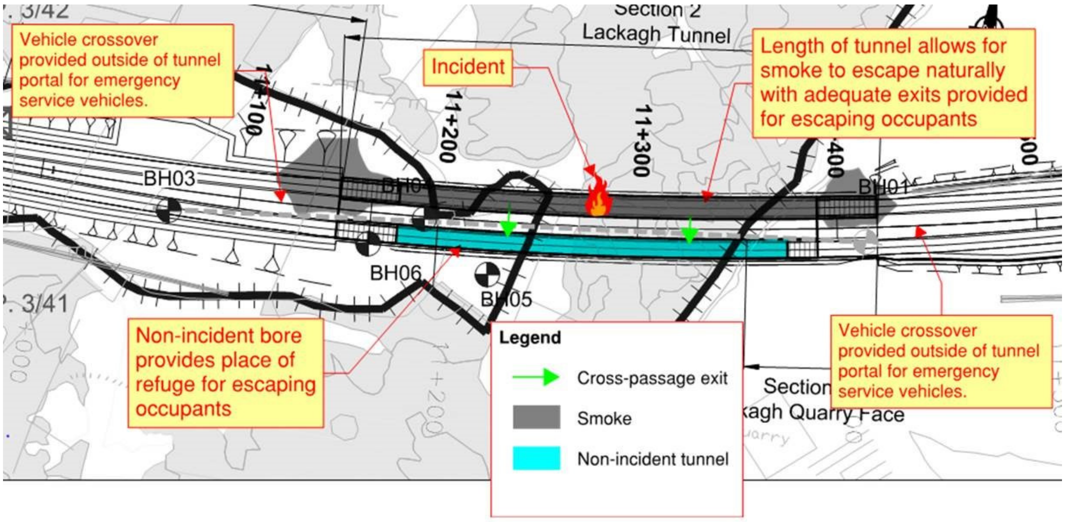
- Due to the geographical location of the tunnels in that there is little industry west of Galway City, it is not expected that a significant number of Dangerous Goods Vehicles (DGVs) will use the tunnels.
- Traffic having to change lanes increases the risk of collision and therefore a fire. There are no junctions, interchanges or lane changes within or in close proximity to the tunnel.
- The bore of each tunnel is separated by approximately 8m, and a mined cross passage will be provided at locations where escape points are required, to provide access between tunnel bores.
- A traffic control system shall be put in place as described in section 4.7.3. The traffic control system shall provide management with the ability to detect potential congestion or queuing approaching the tunnel in order to take the necessary action. Barriers and signage shall be put in place to allow the closure of a lane, bore or tunnel as needed.
- Fire Fighting Water Storage Tanks have been designed to provide water from 2 no. hydrants at a flow rate of 33 l/s per hydrant for a duration of 1 hour. (This is from BD78/99 – Suggests to confirm that this is adequate with Local Fire Fighting Authority)
- A drainage system will be provided for accidental spillage of hazardous materials. A 25m3 impounding drainage sump, in accordance with HD33/15, will cater for a spillage of hazardous liquid from one road tanker. This will be located adjacent to the pump sump and station which are located at the low point of the alignment and outside of both tunnel structures. The impounding drainage sump can be isolated and evacuated manually to a bowser vehicle for appropriate disposal independently of the main pumps or discharge pipework.

For further information, refer to Section 4.6.

3.13.3 Means of escape

In the unlikely event that occupants do need to evacuate in the case of fire, they can do so via the portals or via cross-passage doors into the adjacent tunnel from where they can walk to one of the portals or await rescue.

Figure 3.3: Means of Escape



It is currently proposed to provide cross-passage every 100 m in accordance with TII DN-STR-03015 BD78/99. Walkways will be provided on both sides of the tunnel to allow evacuating occupants to access the cross-passage escape doors. The evacuation scenario is illustrated in Figure 3.3.

3.13.4 Structural fire resistance

The structural resistance to fire is also a key aspect of any tunnel due to the high fire loads in such a confined environment. Design is required to rigorous fire curves (temperature vs. time). The Lackagh Tunnel structure shall be capable of resisting the Rijkswaterstaat (RWS) fire curve for a minimum of 120 minutes. Provisions, such as polypropylene fibre reinforcement or fire protection boards, shall be put in place to reduce the risk of spalling - a phenomenon whereby portions of concrete fall off the tunnel lining during a fire therefore reducing the overall performance of the structure due to reduced concrete depth.

Particular attention needs to be given to the protection of any joints, and in particular sealing element within the joints.

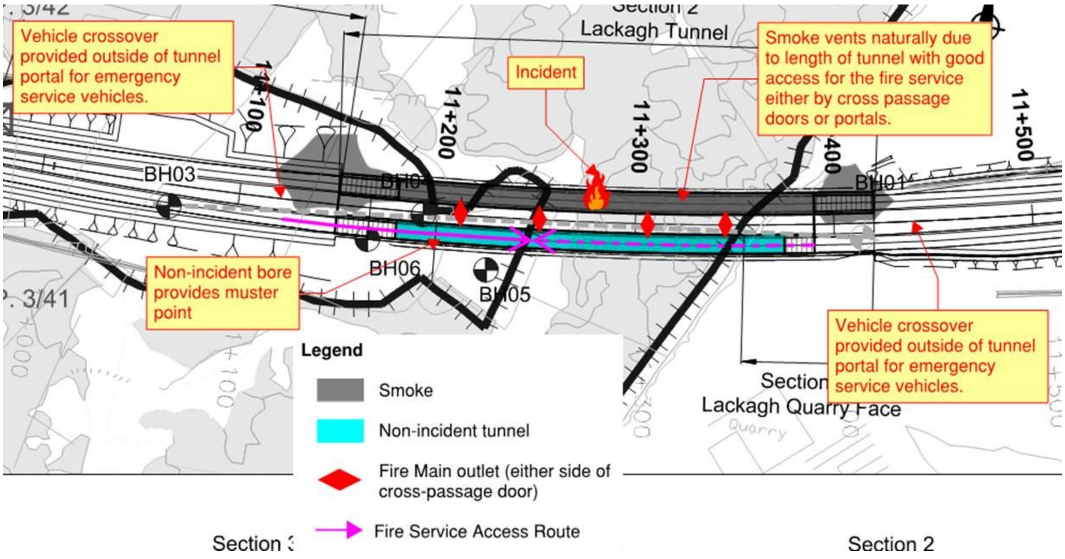
3.13.5 Access and facilities for the fire service

In terms of getting to the Lackagh Tunnel and to the correct bore, the fire service will be able to approach the tunnel from either the east or the west sides. In addition, and to facilitate this solution, a vehicle cross-over will be provided outside, but close to, the tunnel portals. This will allow the fire service to cross onto the opposing traffic lanes should they need to as part of their operational response.

The fire service will be able to access the fire via the non-incident tunnel (if deemed necessary) which should be free from smoke. Short distances between cross-passage doors and the portals will aid fire-fighting operations as well as escape. A wet fire main along with emergency telephones will be provided at regular 50 m intervals along each bore of the tunnel – the fire service may use the main from either bore to fight the fire.

Figure 3.4 below illustrates the provisions for fire service in terms of access and facilities.

Figure 3.4: Fire service access.



3.13.6 Systems

Other tunnel safety systems which will contribute to the management of the tunnel and therefore assist in maintaining adequate levels of safety are as follows:

- CCTV,
- Traffic control measures (see Section 4.7),
- Fire detection (linear heat or similar with manual call points),
- PA system,
- Emergency Lighting System (see 2.15.8 above),
- Signage.

The preliminary design of these systems are dealt within in other sections of this report.

3.14 Tunnel operation and plant control

Refer to sections 2.15, 2.16 and 3.12.

4 Safety

4.1 Traffic Management

During the construction there will be no temporary traffic management measures required as the proposed alignment within Lackagh Tunnel and Western Approach does not impact on any existing roads. The Lackagh Quarry will be used for the site staging area during the works.

4.2 Safety During Construction

4.2.1 Lackagh Tunnel

The Lackagh Tunnel will be a mined tunnel and is expected to be excavated by drill and blast methods. Tunnelling work in general is a relatively risky construction activity compared to other types of work due to the significant consequences of a failure. Due to this, safety during tunnelling work is of key importance. In addition to standard construction site safety practices the following safety precautions are proposed for the construction of Lackagh Tunnel.

- Construction of a safe and stable tunnel portal in the Lackagh Quarry face including the use of sprayed concrete and rock dowels. Supporting this face is critical for protection of tunnelling activities and site staff during the start of construction work. No tunnelling activity will take place prior to the creation of this safe portal.
- Pre-support will be installed at the tunnel portal. These will consist of an array of grouted pipes installed above the tunnel. These allow the first stages of the tunnel excavation to advance with an additional level of support in the crown.
- After each round of excavation / blasting the spoil will be removed by machinery and no person should be allowed to approach the face until the newly exposed rock has been inspected and mapped by a suitably qualified geologist and the appropriate level of temporary support has been installed.
- Where rock is deemed to be suitably strong so that no support is required by design, a 50mm flash coat of shotcrete will be sprayed on the crown to prevent any potential rock fall.

4.3 Safety in Use

During use the tunnel will be used by a significant volume of traffic. The tunnel lining will be designed to support the ground for the design life of the structure. Elements that have been attached to the tunnel lining, such as fans, lights and signage will be regularly inspected to ensure that they are well fixed. An intelligent transport system will be employed in the tunnel so that the traffic can be monitored and motorists can be notified of any potential hazard or accident.

Pedestrian protection will be provided at headwalls and walls in accordance with TII DN-STR-03011 (NRA BD 52). Given the extent of the structure, a 2.4m high palisade fence is proposed.

During inspection and maintenance activities the pedestrian access routes can be utilised along with the relevant traffic management measures necessary for the inspection and maintenance operations.

The tunnel fire safety provisions are described in Section 3.13.

4.4 Lighting

Lighting design shall be as described in Sections 2.15.7, 2.15.8, 3.12.13, 3.12,14, 3.12.15 and 3.12.16.

4.5 Protection of Tunnel Roof

In the mined tunnel, the tunnel roof is part of the structural tunnel lining and formed from cast in-situ reinforced concrete. It is designed to withstand all normal ground and water loads as well as self-weight and additional loads from fixed elements for the design life.

In the transition tunnel structure the roof forms the top structural element itself.

The highest risk to the tunnel roof is damage caused due to a fire event or an explosion within the tunnel. In these cases it is critical that the tunnel lining can survive such an event giving enough time to allow emergency services to extinguish the fire and evacuate the tunnel. To ensure the stability of the tunnel during such an event the following measures are considered in the design:

- Provision of polypropylene fibres within the concrete mix. With a density of 1-2kg/m^3 the fibres are evenly distributed throughout the concrete with no impact to the strength of the lining. In the event of a fire the fibres melt and create a passage for superheated air within the concrete to escape. This directly prevents explosive spalling of the concrete lining.
- Additional cover / sacrificial concrete will be provided. This extra thickness of concrete on the inside of the tunnel provides a certain thickness that could be removed and replaced after the fire event without changing the base strength of the lining. In addition it adds extra cover to the steel which will prevent it weakening due to the heat.

At the tunnel transition structure, a 75mm minimum protective concrete screed with 2.5% crossfall and 2.5% longitudinal fall will be provided over the tunnel roof waterproofing. Any vehicles necessary to undertake the waterproofing and screed operations must have inflatable rubber tyres to minimise any damage to the concrete and waterproofing. The initial layer of fill over box structures shall be laid with care to avoid damaging the structure or waterproofing underneath. General construction traffic shall not be permitted on the tunnel transition structure roof until a sufficient depth of fill is placed above the twin box structure to adequately spread the load.

4.6 Compliance with EU Road Tunnel Safety Directives

EU Directive 2004/54/EC of the European Parliament and of the Council on minimum safety requirements for tunnels in the trans-European road network. Road tunnels which form part of the trans-European transport network and exceed 500m in length must be designed in accordance with the EU directive 2004/54/EC which has been transposed into Irish law with Statutory Instrument (SI) No. 213/2006. While Lackagh Tunnel is not at the required length the below summarises how the tunnel compares with the EU Direction 2004/54/EC.

- An inspection and maintenance plan shall be adopted for the life of the tunnel. (Article 12)
- A risk assessment shall take place as part of the tunnel construction and operation (Article 13)
- The tunnel is proposed as twin unidirectional which is recommended as the safest type of tunnel. (Annex I – 2.1.2)
- There is no change in the number of lanes before and through the tunnel (Annex I – 2.1.3)
- Longitudinal gradient not above 5% (Annex I – 2.2.2)
- Emergency walkway is provided. (Annex I - 2.3.1)
- Sufficient fire resistance of the structure (Annex I – 2.7)
- Provision of emergency station (telephone and fire extinguishers) (Annex I – 2.10)
- Intelligent transport system including surveillance to be provided. (Annex I – 2.13)

4.6.1 EU directive 2004/54/EC

It is noted that the EU Directive 2004/54/EC (transposed into Irish Law by SI 213 of 2006) does not apply to this tunnel as it is less than 500m.

TII DN-STR-03015 (BD78/99) outlines the requirements for the design of road tunnels. However, it should be noted that the criterion based approach outlined within this standard is now less favoured in Ireland than the risk based methodology put forward for consideration by EU Directive 2004/54/EC. It was therefore agreed with TII that the EU Directive would be used to determine design requirements for the Lackagh Tunnel.

4.6.2 Tunnel categorisation

Tunnels are categorised from A to E using the *“European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR)”*. This categorisation is based on the assumption that there are three major dangers in tunnels: (i) explosions, (ii) release of toxic gas or volatile toxic liquid and (iii) fires. The tunnel category, is assigned by the competent authority (Transport

Infrastructure Ireland (TII) in Ireland) to a given road tunnel for the purpose of restricting the passage of transport units carrying dangerous goods. In Ireland, Dublin Port Tunnel (Category C) is the only tunnel with restrictions on the transit of dangerous goods[3].

There is limited guidance available in Ireland regarding the carriage of dangerous goods in road tunnels. The most relevant precedent is that of the Dublin Port Tunnel. An examination of the Dublin Port Tunnel's guidance on the carriage of dangerous goods identifies objectives which can be applied to the development of the proposed Lackagh Tunnel.

This guidance notes that no article or substance which would be reasonably likely to explode, dangerously react, produce a flame or dangerous evolution of heat or produce dangerous emissions of toxic, corrosive or flammable gases or vapours are permitted to utilise the tunnel. [4] This guidance aligns with that of Tunnel Category C in accordance with the *"European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR)"*.

The recommended tunnel category for the Lackagh Tunnel is C in accordance with the ADR. The considerations which contributed to this decision are as noted within Section 3.13.2 and as follows:

1. Tunnel Category C is recommended due to the expected low frequency of DGV's and the availability of alternative routes.
2. Tunnel Category C is recommended as there would be a need and desire for HGVs to use the tunnel to access retail and service industries throughout the city and county and therefore must be accommodated.
3. An advanced intelligent transport system be implemented so as to control access to the entire network and in particular to the tunnels.

4.7 Communications and traffic control

4.7.1 General Description

Within this section of the Preliminary Design Report an outline of the Communications and Traffic Control systems proposed for inclusion within the tunnel are described. The preliminary design proposed incorporates the traffic control and communications systems both within the tunnel and on its immediate approach. This provides a holistic description of the traffic management and control systems required to facilitate tunnel operations.

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[3] Health and Safety Authority. (2012) Retrieved June 27, 2016 from the World Wide Web: http://www.hsa.ie/eng/Publications_and_Forms/Publications/Chemical_and_Hazardous_Substances/ADR_Carriage_of_Dangerous_Goods_by_Road_A_Guide_for_Business.pdf

[4] National Roads Authority. (2006) Bye Laws for the Dublin Port Tunnel. National Roads Authority.

4.7.2 Design criteria

The design methodology utilised for the preliminary design is based on the following documents:

- TII DN-STR-03015 (BD 78-99), 'Design of Road Tunnels'.
- Directive 2004-54-EC Minimum Safety Requirements for Tunnels.

In addition to the above, where applicable, existing Irish tunnel design practices have been incorporated so as to promote general consistency and driver familiarity.

Note that while TII DN-STR-03015 (BD 78-99) provides some guidance on what systems should be incorporated in a tunnel of this type, the extent and complexity of these systems are subject to the consultation and approval of the Tunnel Design and Safety Consultation Group (TDSCG).

At the time of development of this section of the Preliminary Design Report, the TDSCG had not been formed and hence this section has been developed in the absence of the TDSCG's input or approval.

4.7.3 Traffic management

To facilitate the traffic management of the tunnel, a number of systems are proposed which will enable a tunnel operator to monitor and control the tunnel operations of various operational scenarios.

These systems are essential in terms of:

- Closing a tunnel bore/lane in the event of an incident (or to prevent incident),
- Closing the tunnel bore/lane to facilitate maintenance,
- Reducing/varying the speed limit within the tunnel.
- Dealing with Over-Height Vehicles

The systems proposed to facilitate the tunnel traffic management are as follows:

- Automatic Incident Detection
- CCTV
- Variable Speed Limits/Lane Control Signals
- Over-height Detection
- Barriers
- Traffic Signals
- Variable Message Signs
- Support Systems

Automatic Incident Detection

The tunnel shall include an Automatic Incident Detection (AID) system. The purpose of the AID is to allow the tunnel operator to monitor the live traffic status and be automatically alerted to traffic queuing, slow moving traffic and stopped vehicles. For the purpose of this preliminary design it is assumed that this requirement will be facilitated through the use of induction loops installed on the road surface at a frequency of every 50m on each lane throughout the tunnel, in addition to the exit/entrance of each lane/bore. On the immediate approach to the tunnel, AID will also be installed but at a frequency of every 500m.

Depending on the confidence in the technology and proven use within a tunnel environment, when carrying out the detailed design the induction loops may be replaced by radars or via the use of CCTV video analytics for the purpose of AID.

CCTV

The tunnel and tunnel approach shall be equipped with Closed Circuit Television (CCTV). The CCTV system is essential for tunnel operations, enabling the tunnel operator to visually monitor the tunnel status in real time and enabling informed decisions to be made. The CCTV systems will also allow the tunnel operator to verify any alarms that may be identified by the respective traffic control or SCADA/fire systems.

The CCTV cameras should be IP interfacing with a minimum resolution of P720 and have Pan, Tilt, Zoom (PTZ) functionality, allowing the tunnel operator to adjust viewing angles to cover all aspects of the tunnel. The CCTV system is envisaged to provide full coverage throughout the tunnel and approaches and as a minimum will be located as follows:

- CCTV cameras every 50m within the tunnel, including coverage of the tunnel SOS phones, laybys and any pedestrian crossover points that may be in place.

To facilitate remote monitoring of the following:

- Entrance to the tunnel bores
- Exit of the tunnel bores
- Over-height detection locations
- Over-height detection pull-in locations/barrier for Over-height vehicle escape
- Emergency Roadside Telephone (ERT) on approach to tunnel
- Any Variable Message Signage (VMS)/Lane Control Signals (LCS), traffic signals on approach to the tunnel.

Depending on the confidence in the technology and proven use within the tunnel environment, when carrying out the detailed design the CCTV may also support other tunnel system functions such as Automatic Incident Detection (AID) and automatic fire detection. This functionality may be enabled by sophisticated video analytic techniques that are now becoming available.

Lane Control Signals/Variable Speed Limits

The tunnel shall be equipped with Lane Control Signals (LCS) both within and on approach to the tunnel. The LCS provide the following functions:

- Enable Variable Speed Limits to be implemented.
    - This provides the operator with the facility to slow down traffic in the interest of safety or smoothing traffic flow.
- Enable individual lanes to be closed.
    - This provides the operator with the facility to close lanes within the tunnel in the event of an incident, or to facilitate maintenance.

The location of the LCS are envisaged to be located as follows:

- Above each lane at the entrance to the tunnel bore.
- Above each lane, every 50m throughout each tunnel bore.
- Above each lane on the tunnel approach (i.e. final 500m) at three locations.

On the tunnel approach, the LCS shall be located on portal gantries and accompanied by one MS4 type Variable Message Sign (VMS) to enable additional information to be disseminated to the driver.

In addition to the above, MS3 type VMS will be located approximately 1km in advance of the tunnel entrance. These VMS will provide advance warning of operational status of the tunnel lanes ahead, providing sufficient time for motorists to adjust their speed and driving approach.

Note, all LCS proposed for this project are single sided and are not designed to facilitate contra flow. If contra flow was to be incorporated in to the design, additional LCS would be required to cover the reverse direction in each bore. A revised alignment, VMS, barriers, signals etc. would also be required. The decision on whether to have a contra flow option should be a subject of discussion for the TDSCG.

Over-height Detection

Key to the operational success of the tunnel is to ensure that appropriate systems and procedures are in place to manage over-height vehicles. An over-height vehicle entering a tunnel poses a significant risk to the tunnel operations, infrastructure and general health/road safety.

To protect the tunnel against such risk, an ‘Over-Height Vehicle Detection’ system shall be utilised. The system has 3 main functions: the detection of the violating vehicle, provide effective communications to the driver to encourage diversion to an alternative route and safely closing the tunnel to prevent the over-height vehicle from entering.

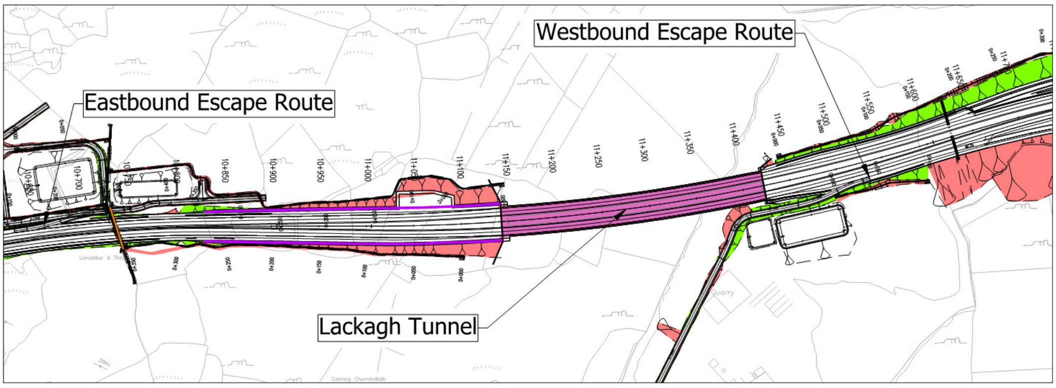
On detection of an over-height vehicle, the violating vehicle driver will be prompted to take an alternative route via the use of VMS. Both the Over-Height Vehicle Detection system and VMS will be located at strategic locations in advance of the tunnel providing the driver with ample opportunity to take an alternative route. The system will also utilise Automatic Number Plate Recognition (ANPR) cameras to assist in providing a targeted message to the violating driver by making reference to the vehicles registration plate on the VMS display.

In the event that the over-height vehicle ignores all visual warnings provided by the VMS, the system will automatically initiate a safe tunnel shutdown procedure utilising the LCS, VMS, traffic signals and barriers at tunnel entrance to prevent the over-height vehicle from entering. The operator will be able to verify the existence of an over-height vehicle at the respective locations via the use of CCTV.

Advisory messages will be displayed to all drivers through the use of the schemes VMS both at the tunnel entrance and in advance, so as to keep all drivers informed of the tunnel status. In addition, the VMS in advance of the tunnel will also guide the over-height vehicle to a purpose built over-height exit point.

In the vicinity of the exit there will be an escape road with access controlled by a barrier as monitored and controlled by the tunnel operator. The escape road diverts the over-height vehicle to an alternative route (i.e. either an adjacent road, or sends the vehicle over the tunnel entrance and back in its direction of origin). Details of the diversion route in both the eastbound and westbound direction are shown on Figure 4.1 below.

Figure 4.1: Over-height vehicle escape roads



The operator shall be able to monitor the over-height vehicle and barrier via a CCTV camera and communicate with the driver via an Emergency Roadside Telephone strategically located in the vicinity of the escape barrier.

Once the over-height vehicle is dealt with, the operator can initiate the re-opening of the tunnel to continue normal operations.

Barriers

As referred to in the above sections, there are two barrier types proposed for the scheme, namely:

- Barrier at escape road(s) for to cater for Over-height Vehicles
- Barrier at each tunnel entrance.

Each of the above barriers will be remote controlled by the tunnel operator, with the tunnel barrier system being designed to automatically engage preprogramed shutdown scenarios in the event of certain incidents (i.e. fire, queuing traffic, vehicle incident etc.) The tunnel operator will also have the facility to override and directly control the barriers as required and can verify their status via CCTV. The barriers will also have the facility to manually open/closed and be locked in place by maintenance/operational staff as required.

Traffic Signals

A three aspect traffic signals (Green, Amber, Red) will be provided either side of the carriageway at each tunnel entrance. The function of the traffic signal is to indicate the status of the tunnel bore with the red aspect indicating that the tunnel is closed and the green aspect indicating the tunnel is open. These messages will be reinforced by the status of the LCS, barriers and the display on the entrance VMS.

Variable Message Signs

As referred to in the above sections there are a number of VMS to be located on approach to the tunnel. The VMS are strategically located and provide the tunnel operator with an essential tools for dissemination of information to drivers.

The VMS envisaged to form part of this tunnel design are as follows:

- One VMS (MS4 type) at each tunnel entrance.
- One VMS (MS3 type) downstream of each Over-Height Vehicle Detection location.
- One VMS (MS4 type) on each LCS portal gantry (i.e. 3no. MS4 type VMS in advance of each tunnel entrance).
- One VMS (MS3 type) located at approximately 1km in advance of the tunnel entrance.

The VMS are envisaged to be controlled via the tunnel traffic control system and preprogramed for various tunnel operational scenarios. Alternatively, the tunnel operator can apply free text to the VMS to suit the particular status of the tunnel.

All VMS will be remotely monitored by the tunnel operator, with CCTV being strategically located to ensure that VMS messages displayed can be visually verified.

In addition to the above the tunnel operator is also envisaged to have the facility to utilise other strategically located VMS across the road network to facilitate a more holistic approach to traffic management on the TII road network.

System Support Infrastructure

To facilitate the traffic control systems described in this section it is envisaged that an optical fibre network shall be installed throughout each tunnel bore and on the approaches. The purpose of the optical fibre network will be to provide secure and resilient connectivity between each of the tunnel systems roadside infrastructure and the main tunnel control systems.

The Information and Communication Technology (ICT) infrastructure to support the tunnel systems (i.e. servers, leased lines, equipment racks, switches, UPS) are envisaged to be housed with the TSB located in the vicinity of the tunnel.

4.7.4 Telephone system

The tunnel bores will equipped with SOS phones installed throughout each tunnel bore and will enable drivers/users to initiate audio communications directly with the tunnel operator in the event of an accident/breakdown.

The SOS phones will be located at 50m intervals throughout the tunnel and at each tunnel entrance and exit. In addition, SOS phones will be installed at the escape road barrier location/over-height vehicle exit points, to facilitate communications/instructions to be provided from the tunnel operator to the over-height vehicle driver.

In addition to the SOS phones, the scheme and tunnel approach will be supplemented with the equivalent Emergency Road Telephones (ERT) located at intervals no greater than 2km and in line with the TII CC-SPW-01500.

4.7.5 Emergency procedures

The traffic control systems will provide the tunnel operator with the facility to monitor and control vehicular access to the tunnel via technologies such as the VMS, LCS, Traffic signals and the barriers described. These can be utilised by the tunnel operator to initiate various emergency tunnel operational procedures in the event of an emergency and incident (i.e. accident, pedestrian within tunnel, fire etc.).

4.7.6 Traffic signs

Fixed traffic signs shall be provided in advance of the final junction before the tunnel on both approaches to the tunnel. These advanced fixed signs shall inform road users of the following:

- The tunnel ahead.
- The tunnel height.
- Restrictions on traffic permitted through the tunnel.
- Alternative route(s) for over-height vehicles and vehicles not permitted through the tunnel.

Fixed traffic signs shall be provided between the final junction and the tunnel portals on both approaches to the tunnel. The advanced signage shall inform road users:

- The tunnel ahead.
- The tunnel height.
- The tunnel length.
- Restrictions on traffic through the tunnel.
- An advanced direction sign indicating an emergency escape route for over-height vehicles ahead.

- A direction sign indicating the location of the emergency escape route for over-height vehicles.

4.7.7 Traffic monitoring

As part of the tunnel design it is envisaged that the monitoring and control of the tunnel operations shall be carried out remotely by a tunnel operator. The tunnel operator will have full access to the tunnel systems and CCTV both in the tunnel and on its approaches. This will enable the operator to make informed decisions throughout a variety of tunnel operational scenarios. It is envisaged that the tunnel operator will be located at the Dublin Tunnel Control Building and will have full access to the tunnel systems.

5 Cost

5.1 Budget Estimate in current year, including whole life

5.1.1 Construction Cost Estimate

The cost estimate for the Lackagh Tunnel has been prepared using typical cost per metre rates for the envisaged tunnel configuration, tunnel cross section, materials, and construction methodology and maintenance requirements. These costs do not include general work items, such as site clearance, fencing, road markings and signs and road pavement as these costs are considered as part of the overall scheme costs. Preliminaries, such as mobilisation costs, were considered for the Lackagh Tunnel estimate as they can be a very significant element of cut and over tunnelling construction. The estimated costs were compared against completed outturn tunnelling projects**.** This information is based on an internal Arup study completed as part of the development of the Dublin Eastern Bypass. This study examined the cost of tunnel delivery in Ireland and across Europe.

The cost of the tunnel is highly dependent on the construction methodology and the temporary works necessary to build the tunnel, in addition to the form of construction.

Table 5.1 Estimated construction costs

Description	**Cost [Million Euros] (Excl. VAT)**
Structure S11-01 (Approach Structure & Tunnel)	36M to 44M

An operation and maintenance cost of €1 million per annum has been assumed in this cost estimate. The operations and maintenance cost for the Lackagh Tunnel calculated over a 60 year period with an average discount rate of 5% is €19 million.

- The whole life cost of the Lackagh Tunnel based on the median capital cost and discounted operations and maintenance cost above is €59 million.

6 Design Assessment Criteria

6.1 Lackagh Tunnel (Mined Tunnel)

6.1.1 Normal load case

Permanent Actions in accordance with IS EN 1991-1-1:2002 and IS EN 1997-1:2004 and the associated National Annexes.

The structure will be designed for Load Models LM1 and LM2 in accordance with IS EN 1991-2:2003 and the associated National Annex.

6.1.1.1 Rock Loads

For shallow rock tunnels the full weight of the rock above and around the tunnel is considered for the design of the permanent lining. During the temporary works and early life of the lining the rock load may not be acting on the lining but it is assumed that the temporary support will eventually fail or weaken and the rock will relax onto the permanent lining.

Where there is a reasonable cover of rock above the tunnel it is not appropriate to assume that the full weight of rock will act on the tunnel because the rock will arch around any openings. For this case the reduced rock loads that are applied to the tunnel permanent support lining are developed in accordance with an empirical rock mass classification system. The NGI tunnelling quality index, Q System, (Barton et al 1974) is used in calculation of rock loads on tunnel permanent lining.

The vertical rock pressure applied to tunnel roof, P_{roof}, is calculated as follows:

$$P_{roof} = \frac{200 J_n^{0.5} Q^{-1/3}}{3 J_r}$$

Where: P_{roof} = vertical rock pressure on tunnel crown (arch) (kPa)

Q = Q-Value

J_n = Joint Set Number

J_r = Joint Roughness

Lateral rock pressure applied to tunnel walls, $P_{wall,}$ is calculated as follows:

$$P_{wall} = \frac{200 J_n^{0.5} Q_{wall}^{-1/3}}{3 J_r}$$

Where: P_{wall} = lateral rock pressure on tunnel wall (kPa)

$$\mathrm{Q}_{wall} = \begin{cases} 5\mathrm{Q}, & \mathrm{Q} \geq 10 \\ 2.5Q, & 0.1 \leq Q < 10 \\ 1\mathrm{Q}, & \mathrm{Q} < 0.1 \end{cases}$$

J_n = Joint Set Number

J_r = Joint Roughness

6.1.1.2 Water Loads

The Lackagh tunnel is designed as a fully undrained or “tanked” tunnel which means that there will be no drainage or other system of water pressure relief that can be relied upon to reduce the water pressure. However, for arching structures the increase of a normal load such as water pressure can sometimes benefit the behaviour of the structure. As a result both maximum and minimum water levels will be considered in the design of the tunnel lining so that the worst case scenario can be determined.

6.1.1.3 Traffic loads

Traffic loads will act vertically on the invert of the tunnel in opposition to any water pressure that may be acting there. Design cases with and without traffic loading will be considered. The structure will be designed for Load Models LM1 and LM2 in accordance with IS EN 1991-2:2003 and the associated National Annex.

6.1.1.4 Internal fixtures

Internal fixtures such as ventilation fans, lights, cladding, etc. are affixed to the lining and will add a load. As the final details of the internal fixtures is not known an assumed pressure will be added to the lining.

6.1.1.5 Surcharge

Any additional load acting on the ground surface above the tunnel is to be considered as adding an additional load to the tunnel lining. Where no existing surcharge is known, then an assumed loading is taken to account for potential traffic or other loading.

6.1.1.6 Future loading

In some instances there may be future development above or adjacent to the tunnel. Such loads should be considered where reasonable. Due to the presence of the cSAC above the tunnel it is not considered that there will be any future loading on the Lackagh Tunnel.

6.1.1.7 Self-weight

The self-weight of the tunnel lining is also considered in the lining design.

6.1.1.8 Wedge loading

In a jointed rock mass, occasionally the joints can be arrange locally so that a wedge of rock can become loose and act independently on the lining. This normally behaves as a local increase in rock load at a point in the lining. Using the geotechnical information and tunnel geometry, a worst case rock wedge can be determined for use in the tunnel loading calculations.

6.1.1.9 Uneven loading

As the arched lining can benefit from even and uniform loading a design case will be added which examines uneven loading due to sloping ground, adjacent one-sided loading, rock wedges, flowing water etc.

6.1.2 Abnormal load case

Load Model 3 up to and including SV196 (where applicable) will be considered in accordance with IS EN 1991-2:2003 and the associated National Annex.

6.1.3 Footway live loading

Where applicable, a footway loading shall be in accordance with Clause 5.3.2.1 of IS EN 1991-2:2003. A nominal q_{fk} = 5kN/m2 will be adopted.

6.1.4 Provision for exceptional abnormal loads

Not applicable.

6.1.5 Any special loading not covered above

6.1.5.1 Fire loading

In the event of a fire within the tunnel the lining will be designed to withstand the worst case scenario, as outline in Section 3.13.4.

6.1.6 Heavy or high load route requirements and arrangements being made to preserve route

Not applicable.

6.1.7 Minimum Headroom Provided

The minimum headroom in the tunnel is 5.3m.

6.2 Western Approach and Tunnel Transition Structure

6.2.1 Normal Loading

Permanent and Transient Actions in accordance with IS EN 1991-1-1:2002 and the associated National Annex.

6.2.1.1 Ground Loads

The U-shaped structure at the Western Approach and any retaining structure will be subject to lateral earth pressures from +17.7OD to the base of the structure. These loads can be determined from the expected ground conditions and the design parameters of the soil, in particular the unit weight and strength parameters.

6.2.1.2 Water Loads

The Western Approach is designed as an undrained structure with a high water cut off at +17.7moD. This water pressure will act on the base of the structure and the load must be resisted to prevent uplift.

6.2.1.3 Traffic loads

Traffic loads will act vertically on the road and onto the base of the U-shaped structure. This load may work in opposition to any water pressure that may be acting there. Design cases with and without traffic loading will be considered.

The structure will be designed for Load Models LM1 and LM2 in accordance with IS EN 1991-2:2003 and the associated National Annex.

6.2.1.4 Surcharge

Any load acting at the back of the slopes or retaining structures is to be considered in the design.

6.2.1.5 Uneven loading

As there may be varying loading conditions on either side of the Western Approach such as a slope on one side and retaining structure on the other it is important that the effect of the uneven loading is examined in the design.

6.2.2 Abnormal loading

Load Model 3 up to and including SV196 (where applicable) will be considered in accordance with IS EN 1991-2:2003 and the associated National Annex.

6.2.3 Footway live loading

Where applicable, a footway loading shall be in accordance with Clause 5.3.2.1 of IS EN 1991-2:2003. A nominal qfk = 5kN/m2 will be adopted.

6.2.4 Provision for exceptional abnormal loads

Not applicable.

6.2.5 Any special loading not covered above

6.2.5.1 Fire loading

In the event of a fire within the tunnel roof will be designed to withstand the worst case scenario, as outline in Section 3.13.4.

6.2.6 Heavy or high load route requirements and arrangements being made to preserve route

Not applicable.

6.2.7 Slopes

All overburden slopes are proposed at a maximum gradient of 1V:2H. Permanent competent rock cut slopes of 1V:1.5H are also achievable. However, due to close proximity of the proposed road development to the Lough Corrib cSAC and Annex I habitat, cut slopes will be interrupted by retaining structures. These are further discussed in **Section 6.2.8**.

6.2.8 Retaining Structures

In order to protect the Annex I habitat and reduce the encroachment within the cSAC, temporary and permanent retaining structures shall be implemented along the Western Approach.

Where the final excavation level and its associated self-supporting soil slopes encroach upon the cSAC boundary or Annex I habitat, temporary retaining measures are proposed. These include rock socketed sheet pile walls.

Where the permanent cut slopes post construction would encroach upon the cSAC boundary or the Annex I habitat, permanent retaining measures are proposed. These include secant pile walls.

The location of these retaining structures are provided in drawings given in Appendix A.

6.3 Authorities Consulted

Consultation with relevant authorities is on-going. The following groups have been contacted as part of the scheme:

- Transport Infrastructure Ireland (TII)
- Galway County Council (GcoC)
- Galway City Council (GciC)
- Galway Fire Services
- Land and home owners

7 Ground Conditions

The ground conditions in the area of the Western Approach and Lackagh Tunnel generally consists of instances of deep deposits of glacial till, silt, organic clay, surrounded by shallow bedrock in the form of outcropping limestone pavement in some areas. Refer to Section 2.8 for further information.

7.1 Geotechnical compatibility with proposed foundation design

The foundation type and details for the Western Approach and Lackagh Tunnel are presented in Section 3.3.5 and structural drawings given in Appendix A.

The western approach will require surface excavation of up to 22.5m below ground level (at the western tunnel portal entrance). The glacial till is anticipated to be firm to very stiff with some occasional cobbles and boulders. Based on available intrusive investigation and geophysical results, some rock excavation is likely required at the western extent of the western approach.

Bedrock level drops significantly approximately 150m west of the western tunnel portal entrance due to the presence of a palaeolandscape feature. Therefore, the alignment will transition between rock to overburden along the western approach.

Where the base of the cutting is within cohesive overburden and where the effective stress changes during unloading of the soil, swelling (heave) of the underlying material is anticipated. The use of ballast, rock anchors and tension piles are required in order to mitigate against such situations.

In accordance with the preliminary slope cutting assessment conducted in Chapter 5, Ground Conditions, Topography and Earthworks of the GCTP Preliminary Design Report, all permanent soil cuttings shall have a maximum gradient of 1 vertical to 2 horizontal. Based on an assessment conducted in accordance with Chapter 5, Ground Conditions, Topography and Earthworks of the GCTP Preliminary Design Report, permanent rock cut slopes of 1V:1.5H and 1V:1H are achievable where intact rock with minor discontinuities are encountered. Suitable rock stability measures may be implemented where steeper slopes are required or where instability or poor rock quality is encountered during the construction process. These support measures which can be implemented are described in the Lackagh Tunnel Report GCOB-4.03-03-4.13.

The excavation process may expose karst features within the construction footprint. As features can extend both vertically and laterally into the surrounding region, any feature encountered shall be isolated. A methodology for the evaluation and treatment of karst features shall be conducted in accordance with the Construction Environmental Management Plan (CEMP). Probing is required ahead of the tunnel face in order to identify any potential cavities and adequately mitigate against possible instability caused due to such features.

An 8m rock cover will form an effective rock arch and to ensure stability of the tunnel in the temporary case. A 7m minimum separation between bores will provide an adequate arching effect.

Uncontaminated soil and stone materials which are not suitable for re-use will be disposed of to an appropriate site which is permitted under the Waste Management (Facility Permit and Registration) Regulations 2007 and (Amendment) Regulations 2008, 2014, 2015 to accept soil and stone.

7.2 Hydrogeological compatibility with proposed foundation design

Groundwater levels fluctuate between summer lows of 8.2m OD and winter highs of 15.7m OD. Incident rainfall on the rock surface above the tunnel recharges to ground with zero surface runoff. The recharge is carried by pathways through the unsaturated zone and to the water table.

The tunnel design incorporates mitigation to accommodate both the seasonal range of the groundwater table and the recharge pathways from surface to water table. The tunnel design includes sealing of the complete circumference to prevent groundwater ingress both from peak groundwater levels but also from recharge downward to the water table. Sealing of the tunnel circumference may cause recharge inflows to be diverted around the structure but will not prevent flows from reaching the water table.

During construction mitigation measures will be required to accommodate any recharge inflows from the roof. Where inflows occur they should be allowed to infiltrate to ground in the tunnel rather than being pumped out to surface. This is to ensure that recharge is maintained within the appropriate groundwater body.

8 Drawings and Documents

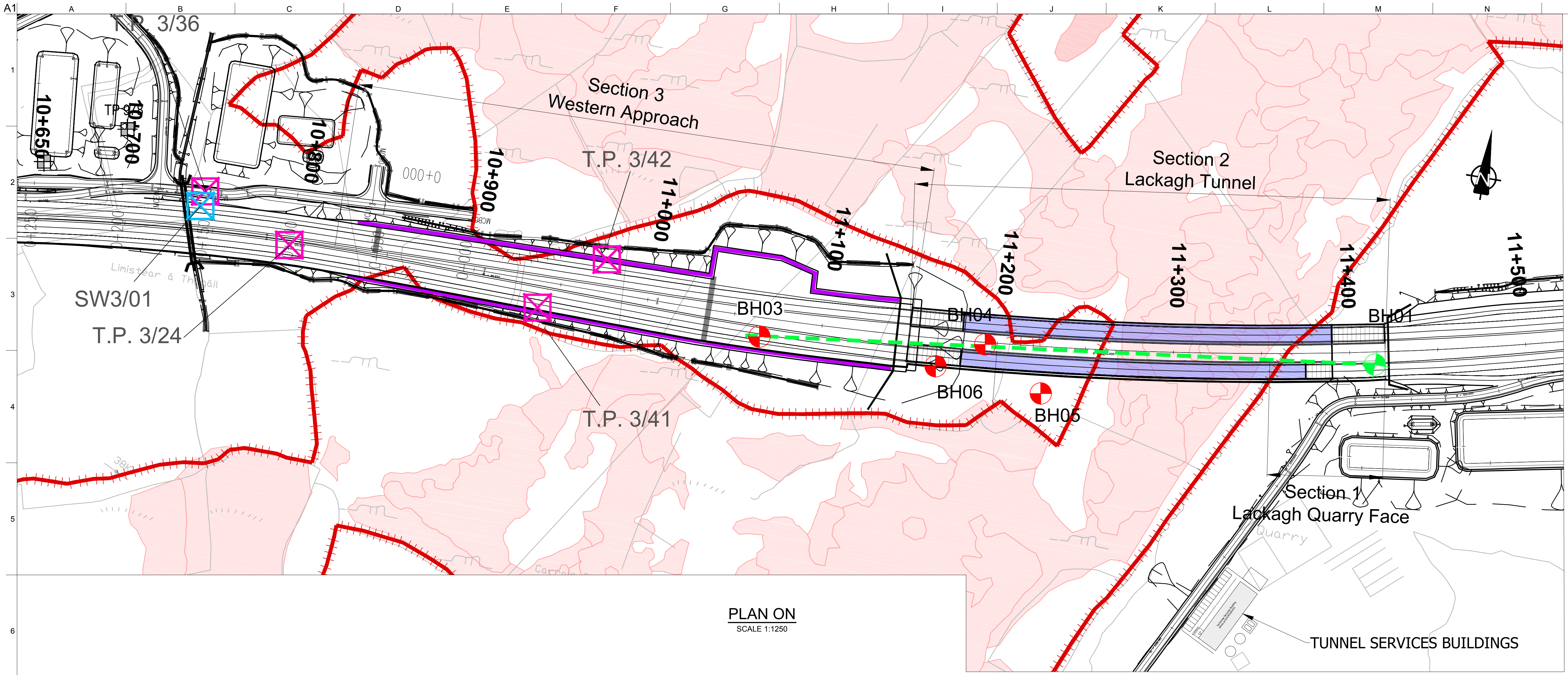
List of all documents accompanying the submission

Drawing No.	**Drawing Title**
GCOB-1700-D- S11-01-001	Lackagh Tunnel and Western Approach Plan and Profile
GCOB-1700- D-S11-01-011	Lackagh Tunnel and Western Approach Mined Tunnel General Arrangement
GCOB- 1700-D-S11-01-013	Lackagh Tunnel and Western Approach Tunnel Temporary Support Details
GCOB-1700-D-S11-01-020	Lackagh Tunnel and Western Approach Western Approach – Plan and Elevation
GCOB-D-1700-S11-01-021	Lackagh Tunnel and Western Approach Western Approach – Sections Sheet 1 of 4
GCOB-D-1700-S11-01-022	Lackagh Tunnel and Western Approach Western Approach – Sections Sheet 2 of 4
GCOB-1700-D-S11-01-023	Lackagh Tunnel and Western Approach Western Approach – Sections Sheet 3 of 4
GCOB-D-1700-S11-01-024	Lackagh Tunnel and Western Approach Western Approach – Sections Sheet 4 of 4
GCOB-1700-D-S11-01-025	Lackagh Tunnel and Western Approach Western Approach – Transition to Lackagh Tunnel
GCOB-1700-D-S11-01-026	Lackagh Tunnel and Western Approach Western Approach – Typical Details
GCOB-1700-D-S11-01-027	Lackagh Tunnel and Western Approach Western Approach – Water Storage Facility
GCOB-1700-D-S11-01-030	Lackagh Tunnel and Western Approach Eastern Approach Plan & Elevation
GCOB-1700-D-S11-01-040	Lackagh Tunnel and Western Approach Portals

Appendix A

Drawings

DESIGN REPORT



PLAN ON

SCALE 1:1250

Legend:

Plan

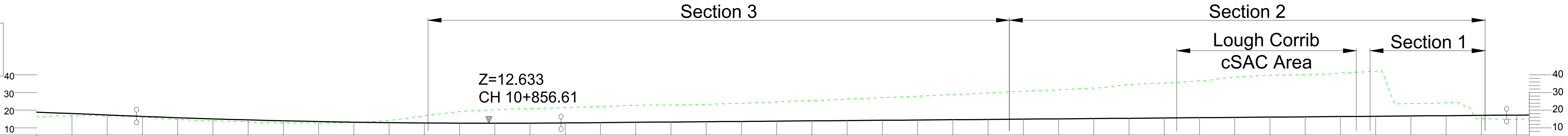
▤	Proposed Geometry Plan
▤	Proposed Tunnel Section
▭	Proposed Tunnel Entrance Portal Structures
═	PED
┼┼┼	Lough Corrib cSAC Boundary
🟥	Annex I Habitat
●	Borehole
●	Horizontal Borehole
☒	Trial Pit
☒	Soakaway

Profile

- - -	Existing Ground (Indicative Levels based on 2m grid LiDAR Data DTM.)
──	Proposed Geometry Profile

MODEL: MLN EAST D15
M-STRING: MC10
DESIGN SPEED: 100 KM/H

SCALE: 1:2500/250
DATUM=6.00



CHAINAGE	10+600	10+620	10+640	10+660	10+680	10+700	10+720	10+740	10+760	10+780	10+800	10+820	10+840	10+860	10+880
PROPOSED LEV	18.82	18.02	17.22	16.44	15.74	15.12	14.56	14.08	13.67	13.33	13.07	12.88	12.76	12.72	12.74
GROUND LEV.	16.47	16.77	16.54	15.64	14.50	14.15	13.18	12.98	12.85	13.23	14.42	17.31	19.54	20.67	20.88
HORIZ. SCHEM.	R=1440.00 L=487.26											CL=48.83		D=194.76	
VERT. SCHEM.	L=95.00 P=-4.00%		R=5500.00 L=265.01												
SUPER. SCHEM.					S=2.5%			S=2.5%			S=2.5%				
GRADIENT (%)	-4.00	-4.00	-4.00	-3.86	-3.50	-3.14	-2.77	-2.41	-2.05	-1.68	-1.32	-0.96	-0.59	-0.23	0.14

CHAINAGE	10+900	10+920	10+940	10+960	10+980	11+000	11+020	11+040	11+060	11+080	11+100	11+120	11+140	11+160
PROPOSED LEV	12.84	13.00	13.16	13.33	13.49	13.66	13.82	13.98	14.15	14.31	14.47	14.64	14.80	14.97
GROUND LEV.	21.54	22.19	22.83	23.03	23.31	24.05	25.04	25.59	26.46	27.22	28.09	29.00	29.97	30.77
HORIZ. SCHEM.									CL=105.00					R=-2040.00 L=378.02
VERT. SCHEM.	P=0.82% L=527.16													
SUPER. SCHEM.		S=2.5%			S=2.5%					S=2.5%				
GRADIENT (%)	0.50	0.79	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82

CHAINAGE	11+180	11+200	11+220	11+240	11+260	11+280	11+300	11+320	11+340	11+360	11+380	11+400	11+420	11+440
PROPOSED LEV	15.13	15.29	15.46	15.62	15.78	15.95	16.11	16.27	16.44	16.60	16.77	16.93	17.09	17.26
GROUND LEV.	31.65	32.79	34.44	35.23	36.65	38.03	39.28	39.96	40.61	24.73	24.26	23.90	14.77	14.92
HORIZ. SCHEM.														
VERT. SCHEM.														
SUPER. SCHEM.										S=2.5% S=2.5%				
GRADIENT (%)	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.83

San áireamh tá sonraíocht Shuirbhéireacht Ordanáis Éireann arna atáirgeadh faoi Cheadúnas OSI Uimh. 2010/17CCMA/Comhairle Contae na Gaillimhe.
Sáraíonn atáirgeadh neamhúdaraithe cóipcheart Shuirbhéireacht Ordanáis Éireann agus Rialtas na hÉireann. © Suirbhéireacht Ordanáis Éireann, 2010.

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Clients

Comhairle Chontae na Gaillimhe
Galway County Council

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Scale: 1:2500 @ A3

Date: February 2017

Issue	Date	By	Chkd	Appd
I2	14/09/2017	DC	PS	JC
I1	27/02/2017	DC	PS	JC

Drawing Title
Lackagh Tunnel and Western Approach
General Plan & Profile

Drawing Status
For Information

Job No	Drawing No	Issue
233985	**GCOB-1700-D-S11-01-001**	**I2**

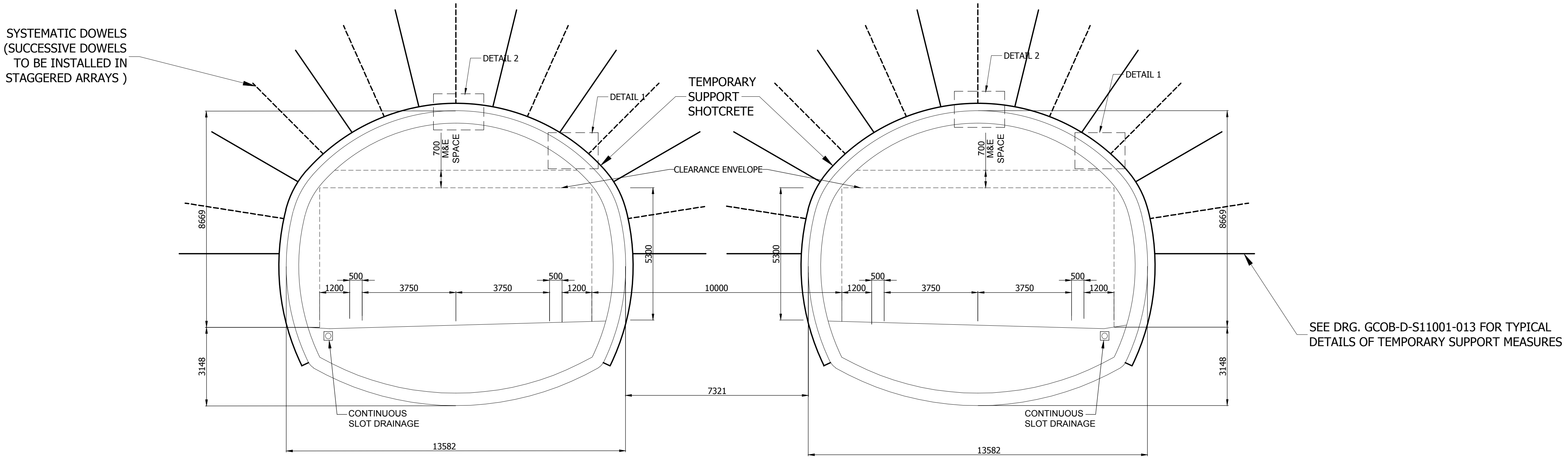
Do not scale

\\global\europe\Dublin\Jobs\233000\233985-00\4. Internal\4-02 Drawings\4-02-8 Highways\8.3 Design Rep\1700 STR\GCOB-D-S11-01-001.dwg

DESIGN REPORT

NOTES:

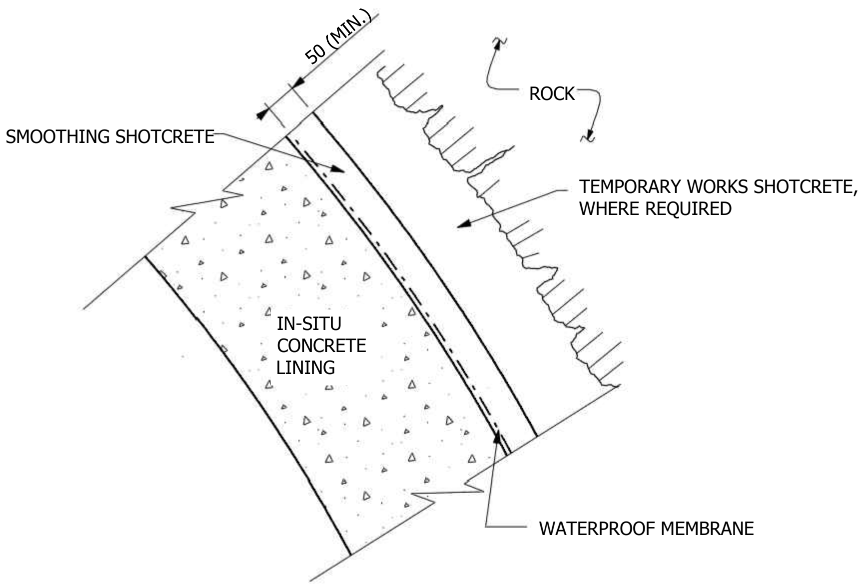
1. ALL DIMENSIONS IN MILLIMETERS UNLESS OTHERWISE STATED.
2. DRAWING TO BE READ IN CONJUNCTION WITH ALIGNMENT DRAWINGS AND TUNNEL PLAN AND PROFILE DRAWINGS.



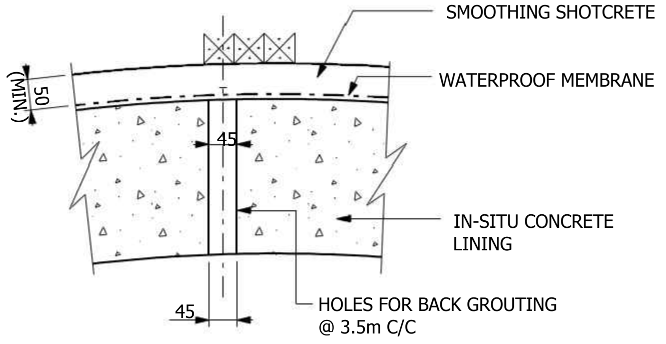
EASTBOUND BORE

WESTBOUND BORE

TYPICAL CROSS SECTION FOR LACKAGH TUNNEL



DETAIL 2



DETAIL 1

Clients

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Galway City
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Turasóireachta agus Spóirt
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Scale
N.T.S.

Date:
July 2016

Issue	Date	By	Chkd	Appd
I3	14/09/2017	KJ	PS	JC
I2	08/06/2017	KJ	PS	JC
I1	27/02/2017	DC	PS	JC

Drawing Title
Lackagh Tunnel and Western Approach
Mined Tunnel General Arrangement

Drawing Status
For Information

Job No	Drawing No	Issue
233985	GCOB-D-S11-01-011	I3

Do not scale
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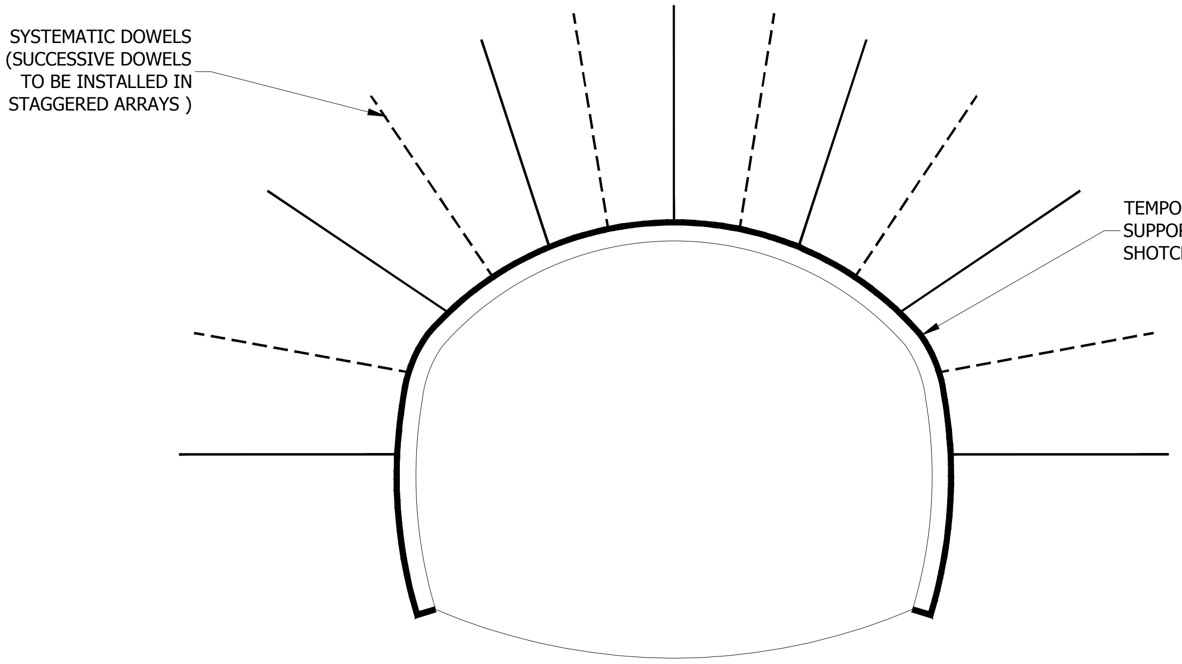
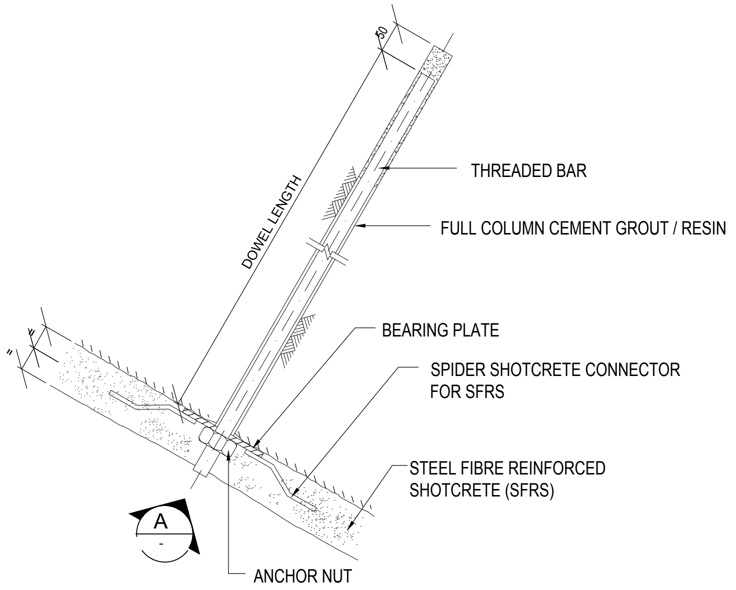
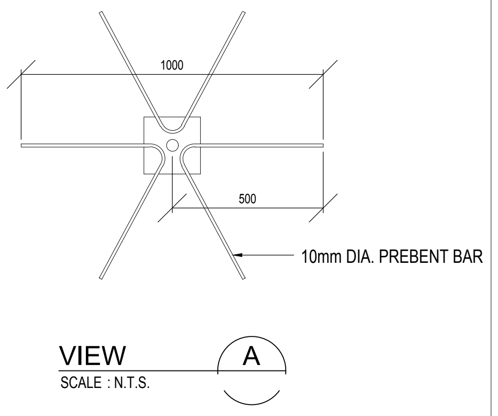
DESIGN REPORT



TYPICAL TEMPORARY SUPPORT CROSS SECTION - LACKAGH TUNNEL





TYPICAL DETAIL OF TEMPORARY CHEMICAL/CEMENT GROUTED ROCK DOWEL

N.T.S.

NOTES:

1. ALL DIMENSIONS IN MILLIMETERS UNLESS OTHERWISE STATED.
2. ON COMPLETION OF EACH ROUND OF EXCAVATION THE EXPOSED ROCK SHALL BE INSPECTED AND MAPPED BY A SUITABLY QUALIFIED GEOLOGIST IN ACCORDANCE WITH THE ROCK MASS CLASSIFICATION Q SYSTEM AND THE SUPPORT DETERMINED ACCORDING TO TABLE A OF THIS DRAWING.
3. ALL SYSTEMATIC DOWELS SHALL BE INSTALLED PERPENDICULAR TO THE EXCAVATED PROFILE.
4. WHERE A LARGE ROCK WEDGE FEATURE OCCURS THE GEOLOGIST WILL ADVISE ON SPECIFIC BOLTING REQUIREMENTS.
5. FOR DETAILS ON THE q-SYSTEM REFER TO:

   [1] BARTON, N., LIEN, R. & LUNDE, J. (1974). ENGINEERING CLASSIFICATION OF ROCK MASSES FOR THE DESIGN OF TUNNEL SUPPORT. ROCK MECHANICS AND ROCKENGINEERING VOL. 6 NO. 4.

   [2] GRIMSTAD E AND BARTON N.R. (1993). UPDATING OF THE Q-SYSTEM FOR NMT. IN INTERNATIONAL SYMPOSIUM ON SPRAYED CONCRETE, FARERNES, NORWAY, NORWEGIAN CONCRETE ASSOCIATION, PP. 46-66.

TABLE A (REFER TO NOTE 5)

SUPPORT CATEGORY	Q (AS MAPPED)	MIN. SUPPORT REQUIREMENT BASED ON Q-VALUE	
		ARCH	
1&2	Q≥3.9	FEATURE DOWELS: SYSTEMATIC DOWELS: SHOTCRETE:	AS NECESSARY NONE 50mm THICK ON LOCAL FRACTURE ZONES
3	1.9≤Q<3.9	FEATURE DOWELS: SYSTEMATIC DOWELS: SHOTCRETE:	AS NECESSARY 4.3m LONG ON A 2.3m GRID 50mm THICK
4	0.6≤Q<1.9	FEATURE DOWELS: SYSTEMATIC DOWELS: SHOTCRETE:	AS NECESSARY 4.3m LONG ON A 2m GRID 70mm THICK
5	0.2≤Q<0.6	FEATURE DOWELS: SYSTEMATIC DOWELS: SHOTCRETE:	AS NECESSARY 4.3m LONG ON A 1.7m GRID 100mm THICK
6-9	<0.2	PRE-SUPPORT AND PASSIVE LINING SYSTEM ON CONSULTATION WITH THE DESIGNER	

Clients
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Galway County Council
N6 Galway City Transport Project
An Roinn Iompair Turasóireachta agus Spóirt
Department Transport, Tourism and Sport
Bonneagar Iompair Éireann
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Scale N.T.S.
Date: July 2016

Issue	Date	By	Chkd	Appd
I2	14/09/2017	KJ	PS	JC
I1	27/02/2017	KJ	PS	JC

Drawing Title
Lackagh Tunnel & Western Approach
Tunnel Temporary Support Details

Drawing Status
For Information

Job No **233985**
Drawing No **GCOB-D-S11-01-013**
Issue **I2**

Do not scale
\\global\europe\Dublin\Jobs\233000\233985-00\4. Internal\4-02 Drawings\4-02-8 Highways\8.3 Design Rep\1700 STR\GCOB-D-S11-01-013.dwg

WESTERN APPROACH & TUNNEL ELEVATION A-A

SCALE 1:500

Clients

Comhairle Chontae na Gaillimhe
Galway County Council

Galway City Transport Project

An Roinn Iompair Turasóireachta agus Spóirt
Department Transport, Tourism and Sport

Bonneagar Iompair Éireann
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Job Title
N6 Galway City Ring Road

Scale: 1:500 @ A1 / 1:1000 @ A3
Date: Febraury 2017

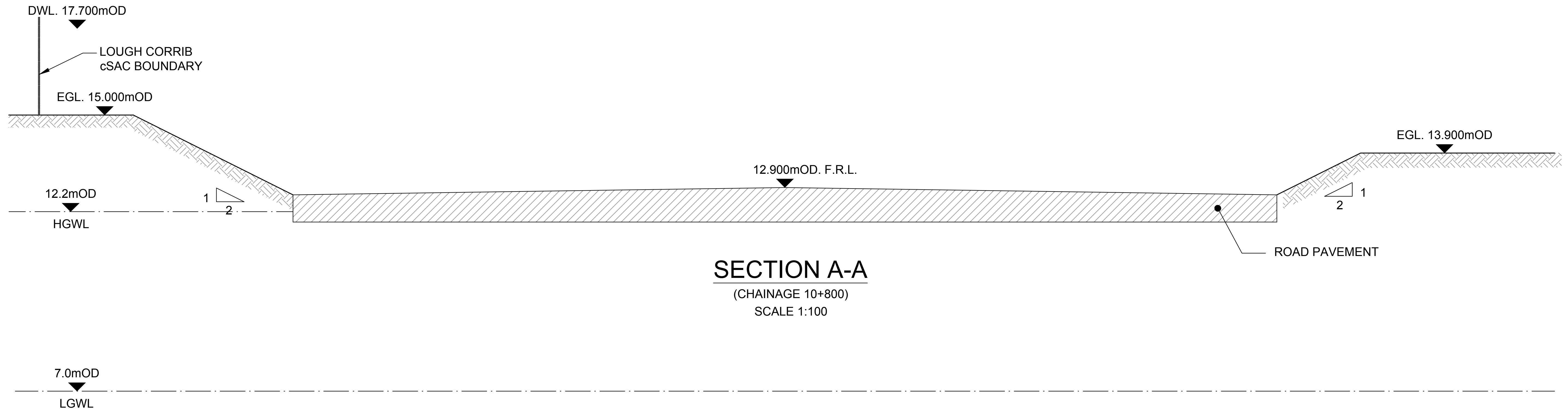
I2	14/09/2017	DC	PM	PM
I1	27/02/2017	DC	PM	PM
Issue	Date	By	Chkd	Appd

Drawing Title
Lackagh Tunnel & Western Approach
Western Approach Plan & Elevation

Drawing Status
For Information

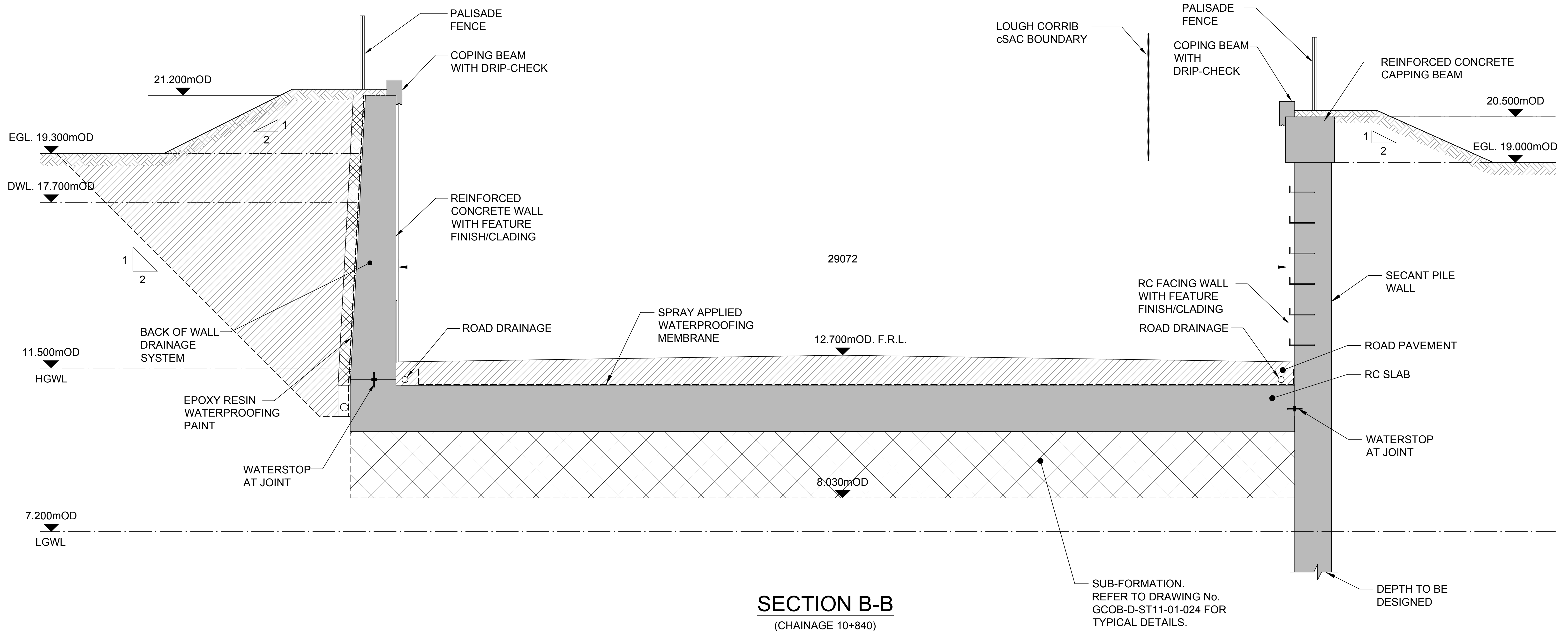
Job No	Drawing No	Issue
233985-00	**GCOB-1700-D-S11-01-020**	**I2**

DESIGN REPORT



SECTION A-A

(CHAINAGE 10+800)
SCALE 1:100



SECTION B-B

(CHAINAGE 10+840)
SCALE 1:100

Legend:

EGL = Existing Ground Level

DWL = Design Water Level

HGWL = High Ground Water Level

LGWL = Low Ground Water Level

NOTE:

1. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS NOTED OTHERWISE.
2. ALL LEVELS ARE SHOWN IN METERS ABOVE ORDNANCE DATUM.
3. FOR TYPICAL DETAILS SEE DRAWING GCOB-1700-D-S11-01-026.

Clients

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Galway County Council

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Job Title
N6 Galway City Ring Road

Scale
1:100 @ A1 / 1:200 @ A3

Date:
Febrauary 2017

Issue	Date	By	Chkd	Appd
I2	14/09/2017	DC	PM	PM
I1	27/02/2017	DC	PM	PM

Drawing Title
Lackagh Tunnel & Western Approach
Western Approach
Sections - Sheet 1 of 4

Drawing Status
For Information

Job No
233985-00

Drawing No
GCOB-1700-D-S11-01-021

Issue
I2

Do not scale

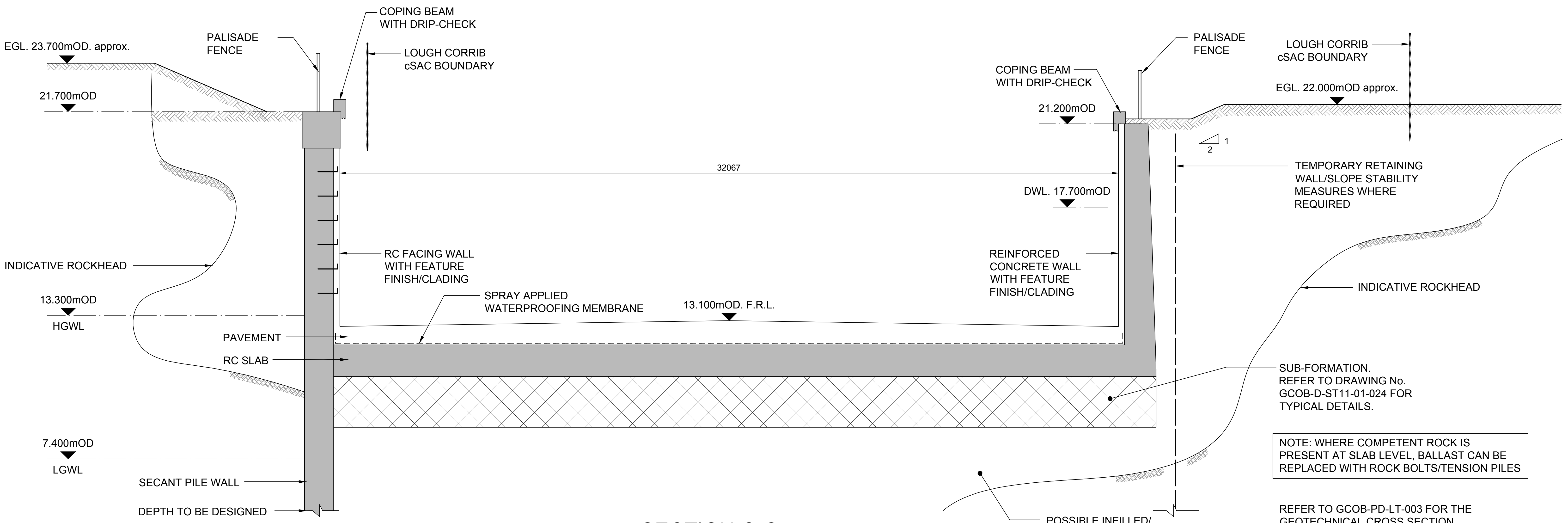
DESIGN REPORT

Legend:

EGL	=	Existing Ground Level
DWL	=	Design Water Level
HGWL	=	High Ground Water Level
LGWL	=	Low Ground Water Level

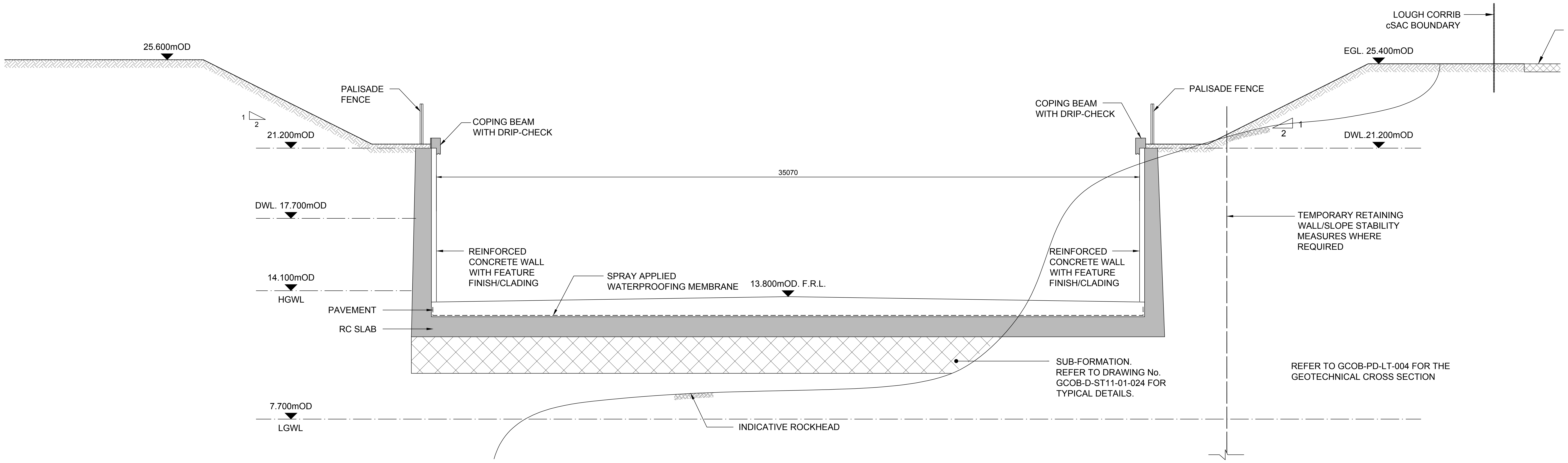
NOTE:

1. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS NOTED OTHERWISE.
2. ALL LEVELS ARE SHOWN IN METERS ABOVE ORDNANCE DATUM.
3. FOR TYPICAL DETAILS SEE DRAWING GCOB-1700-D-S11-01-026.



SECTION C-C

(CHAINAGE 10+930)
SCALE 1:125



SECTION D-D

(CHAINAGE 11+020)
SCALE 1:125

Clients

Comhairle Chontae na Gaillimhe
Galway County Council

Galway City Transport Project

An Roinn Iompair Turasóireachta agus Spóirt
Department Transport, Tourism and Sport

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Job Title
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Scale 1:125 @ A1 / 1:250 @ A3

Date: Febraury 2017

Issue	Date	By	Chkd	Appd
I3	17/10/2017	DC	PM	PM
I2	14/09/2017	DC	PM	PM
I1	27/02/2017	DC	PM	PM

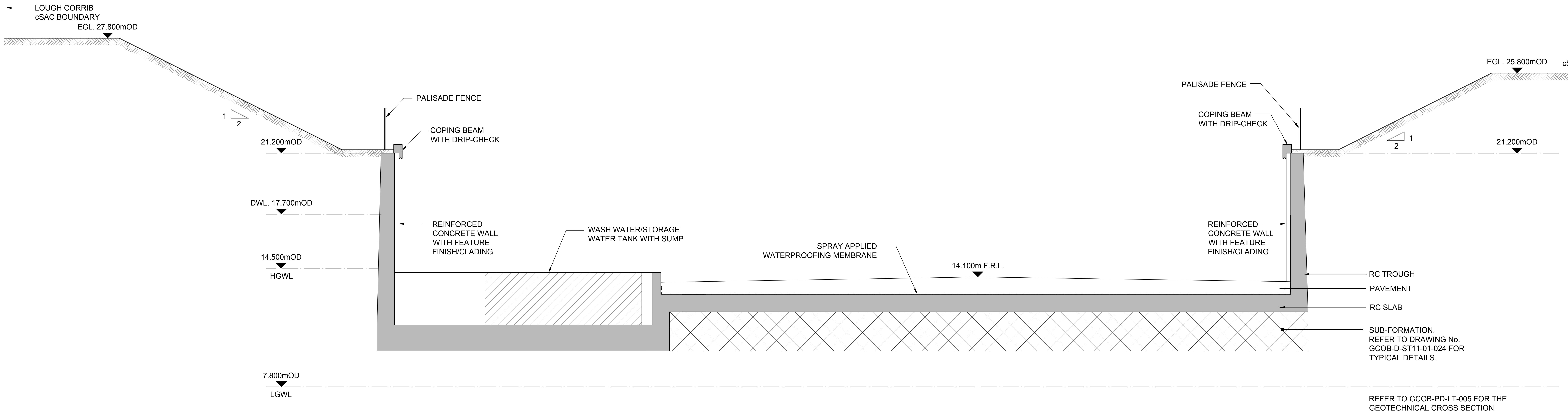
Drawing Title
Lackagh Tunnel & Western Approach
Western Approach
Sections - Sheet 2 of 4

Drawing Status
For Information

Job No **233985-00**
Drawing No **GCOB-1700-D-S11-01-022**
Issue **I3**

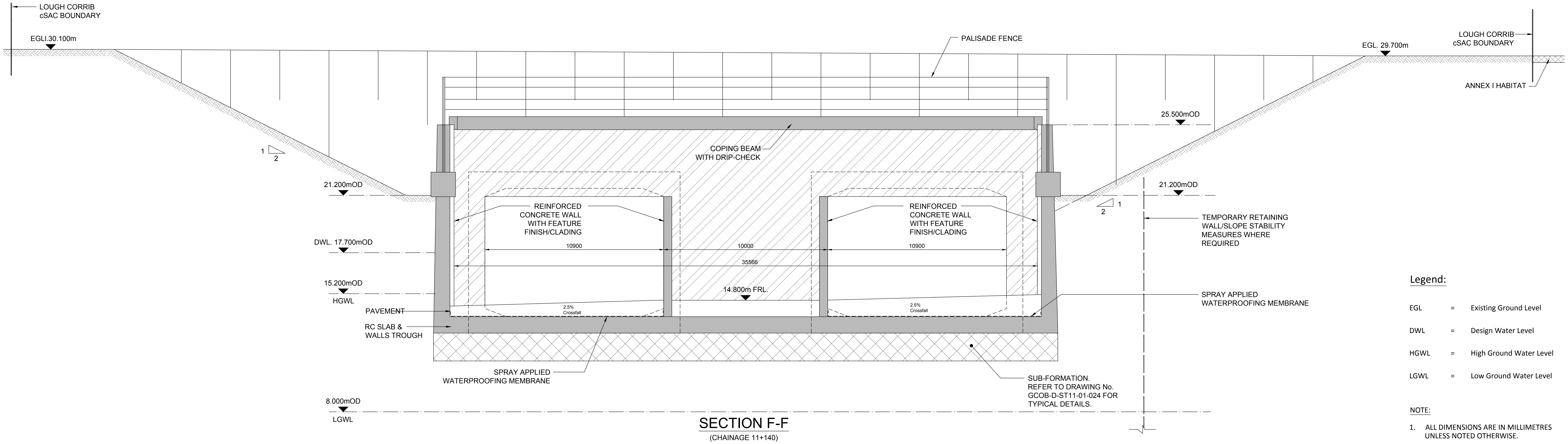
Do not scale

DESIGN REPORT



SECTION E-E

(CHAINAGE 11+060)
SCALE 1:125



SECTION F-F

(CHAINAGE 11+140)
SCALE 1:125

Legend:

EGL = Existing Ground Level
DWL = Design Water Level
HGWL = High Ground Water Level
LGWL = Low Ground Water Level

NOTE:

1. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS NOTED OTHERWISE.
2. ALL LEVELS ARE SHOWN IN METERS ABOVE ORDNANCE DATUM.
3. FOR TYPICAL DETAILS SEE DRAWING GCOB-1700-D-S11-01-026.

Clients
Comhairle Chontae na Gaillimhe
Galway County Council
Galway City Transport Project
Comhairle Cathrach na Gaillimhe | Galway City Council
An Roinn Iompair Turasóireachta agus Spóirt
Department Transport, Tourism and Sport
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Job Title
N6 Galway City Ring Road

Scale 1:125 @ A1 / 1:250 @ A3
Date: February 2017

Issue	Date	By	Chkd	Appd
I3	17/10/2017	DC	PM	PM
I2	14/09/2017	DC	PM	PM
I1	27/02/2017	DC	PM	PM

Drawing Title
Lackagh Tunnel & Western Approach
Western Approach
Sections - Sheet 3 of 4

Drawing Status
For Information

Job No	Drawing No	Issue
233985-00	**GCOB-1700-D-S11-01-023**	**I3**

Do not scale

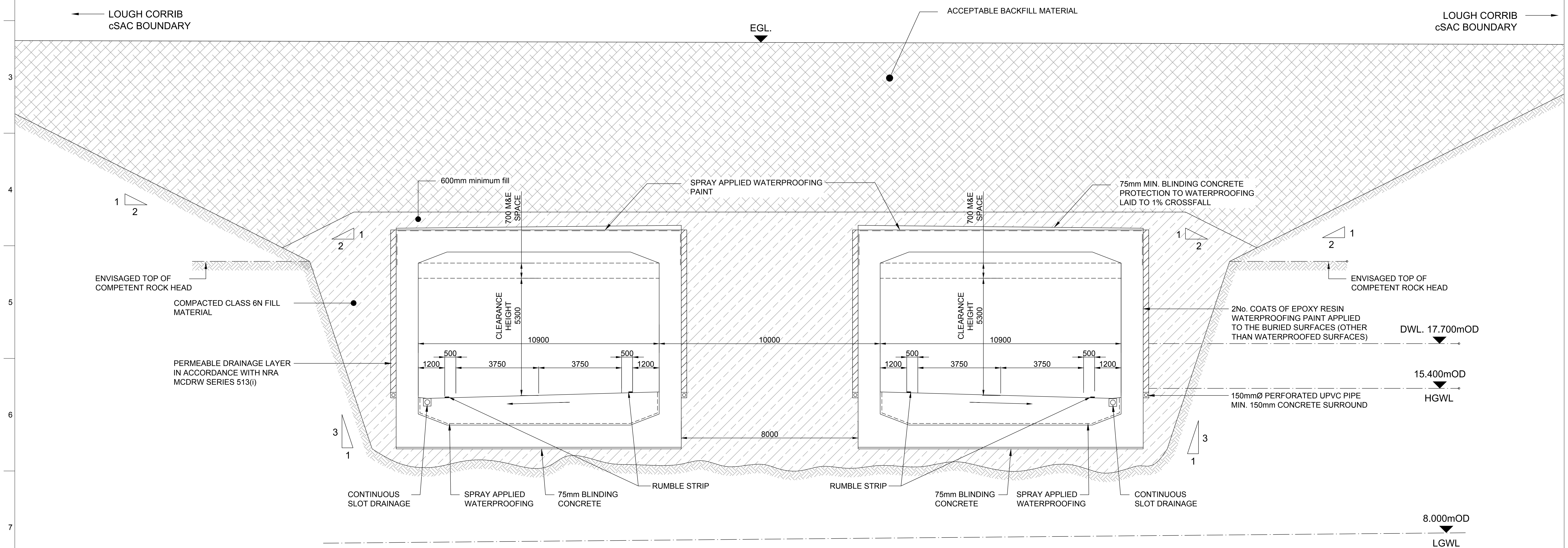
DESIGN REPORT

Legend:

EGL	=	Existing Ground Level
DWL	=	Design Water Level
HGWL	=	High Ground Water Level
LGWL	=	Low Ground Water Level

NOTE:

1. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS NOTED OTHERWISE.
2. ALL LEVELS ARE SHOWN IN METERS ABOVE ORDNANCE DATUM.
3. FOR TYPICAL DETAILS SEE DRAWING GCOB-1700-D-S11-01-026.



SECTION H-H

(CHAINAGE 11+180)
SCALE 1:100

Clients

Comhairle Chontae na Gaillimhe
Galway County Council

N6 Galway City Transport Project

An Roinn Iompair Turasóireachta agus Spóirt
Department Transport, Tourism and Sport

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Job Title
N6 Galway City Ring Road

Scale 1:100 @ A1 / 1:200 @ A3

Date: January 2017

Issue	Date	By	Chkd	Appd
I2	14/09/2017	DC	PM	PM
I1	27/02/2017	DC	PM	PM

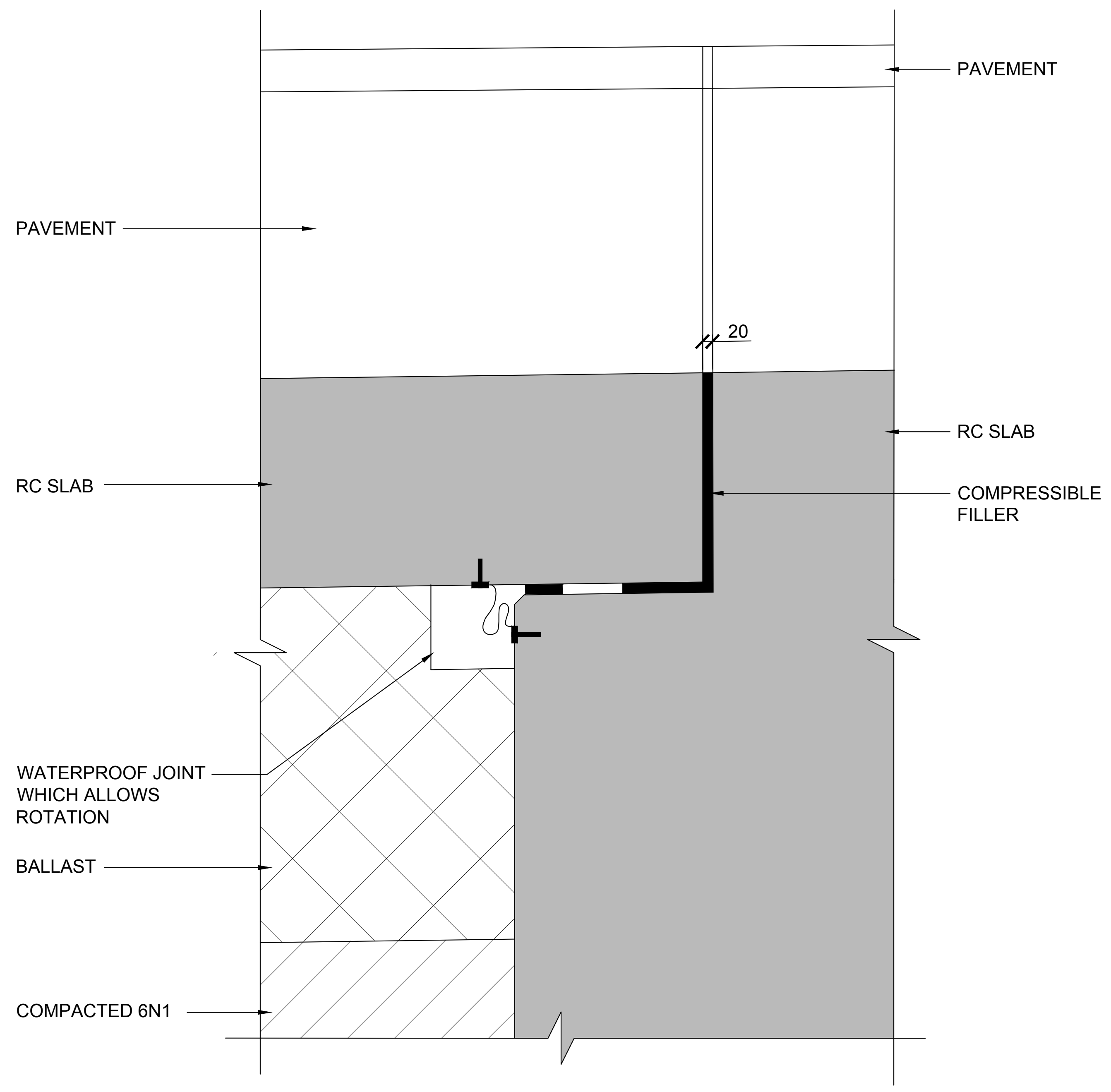
Drawing Title
Lackagh Tunnel & Western Approach
Western Approach
Sections - Sheet 4 of 4

Drawing Status
For Information

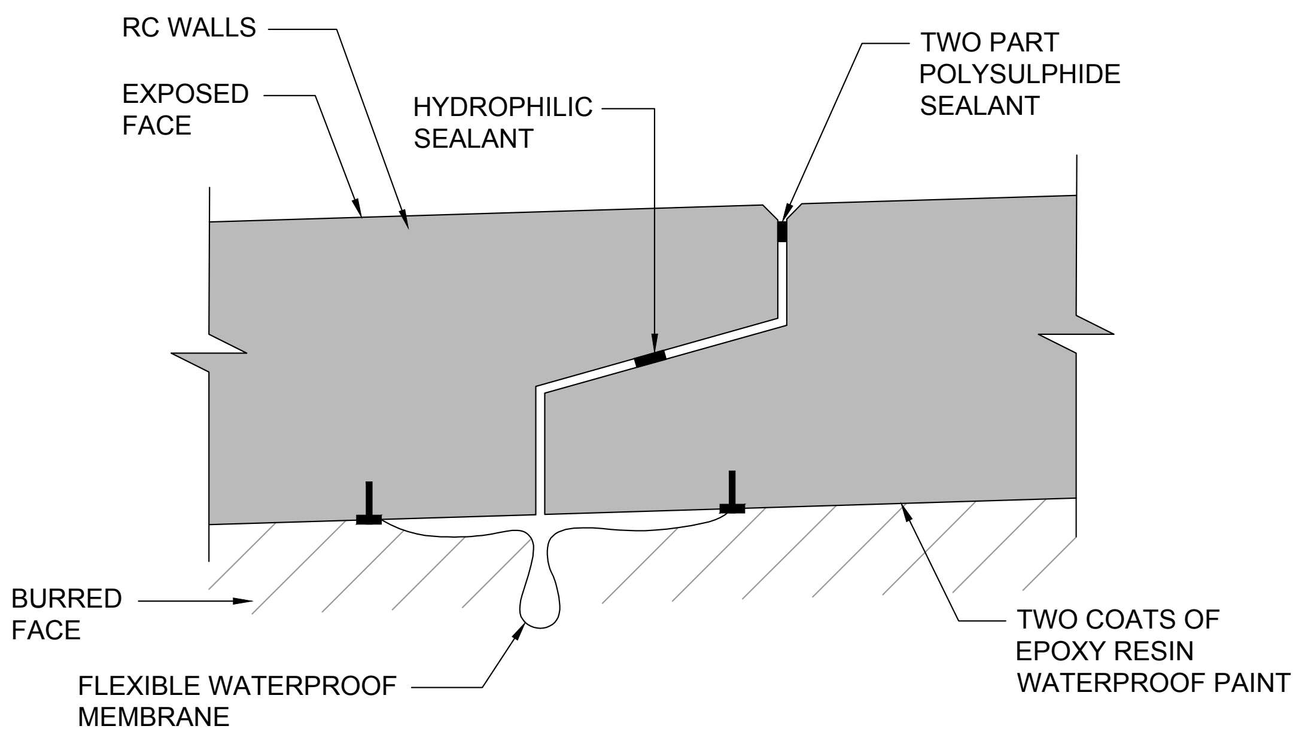
Job No **233985-00**
Drawing No **GCOB-1700-D-S11-01-024**
Issue **I2**

Do not scale

A1



DETAIL A
SCALE 1:25



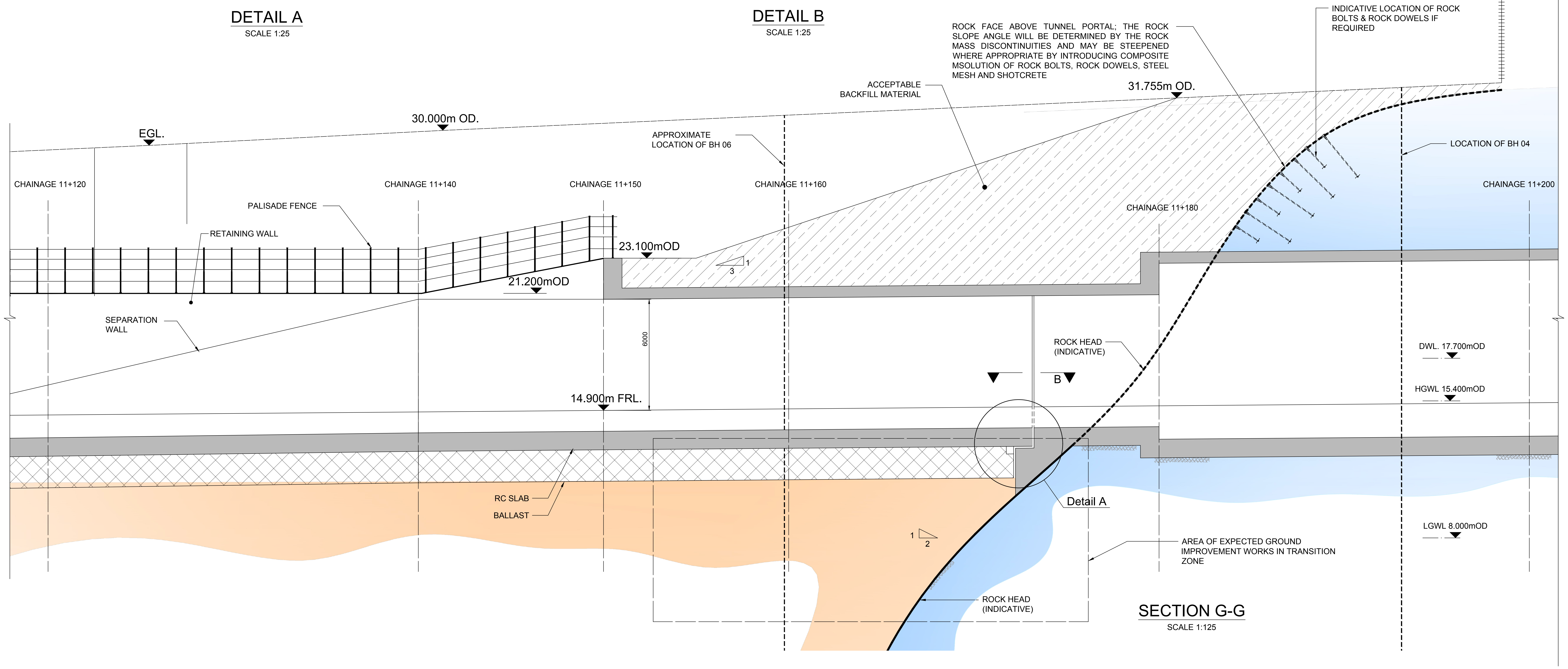
DETAIL B
SCALE 1:25

DESIGN REPORT

Legend:

DWL = Design Water Level
HGWL = High Ground Water Level
LGWL = Low Ground Water Level

- - - - -	Existing Ground Level
──	Top of RC Wall
──	Indicative Rock Head Level
🟦	Limestone Bedrock
🟧	Overburden
▨	Acceptable Backfill Material



SECTION G-G
SCALE 1:125

Clients
Comhairle Chontae na Gaillimhe
Galway County Council
N6 Galway City Transport Project
An Roinn Iompair Turasóireachta agus Spóirt
Department Transport, Tourism and Sport
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Job Title
N6 Galway City Ring Road

Scale 1:125 @ A1 / 1:250 @ A3
Date: February 2017

Issue	Date	By	Chkd	Appd
I3	17/10/2017	DC	PM	PM
I2	14/09/2017	DC	PM	PM
I1	27/02/2017	DC	PM	PM

Drawing Title
Lackagh Tunnel & Western Approach
Western Approach
Transition to Lackagh Tunnel

Drawing Status
For Information

Job No	Drawing No	Issue
233985-00	**GCOB-1700-D-S11-01-025**	**I3**

Do not scale

DESIGN REPORT

NOTE: SUB-FORMATIONS TYPICAL DETAILS VARY.
POTENTIAL OPTIONS:
1. BALLAST
2. TENSION PILES
3. ROCK BOLTS

TYPICAL DETAIL
SCALE 1:50

Clients

Comhairle Chontae na Gaillimhe
Galway County Council

N6 Galway City Transport Project

An Roinn Iompair Turasóireachta agus Spóirt
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Job Title
N6 Galway City Ring Road

Scale: 1:125 @ A1 / 1:250 @ A3

Date: January 2017

Issue	Date	By	Chkd	Appd
I2	14/09/2017	DC	PM	PM
I1	27/02/2017	DC	PM	PM

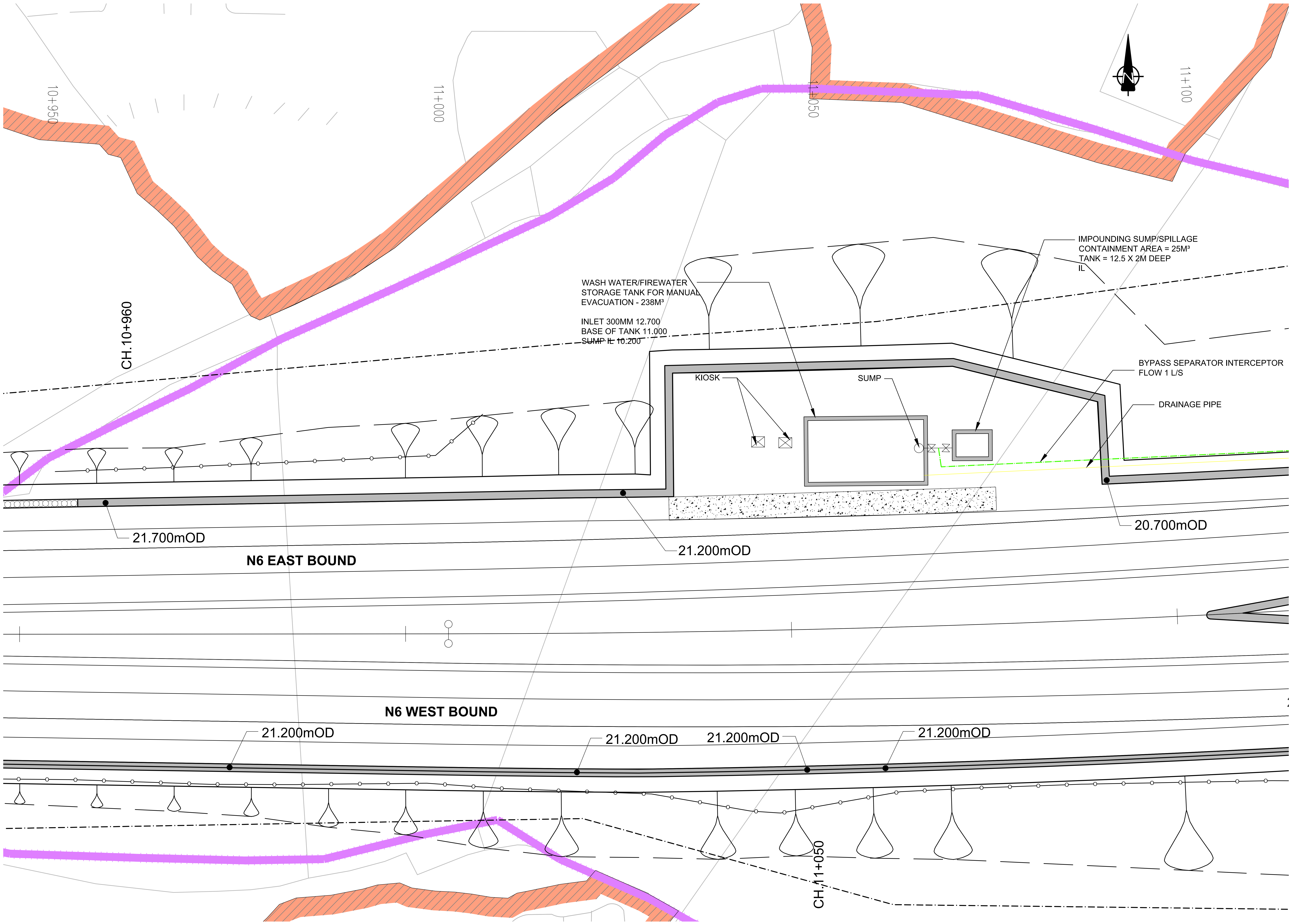
Drawing Title
Lackagh Tunnel & Western Approach
Typical Details

Drawing Status
For Information

Job No	Drawing No	Issue
233985-00	**GCOB-1700-D-S11-01-026**	**I2**

Do not scale

DESIGN REPORT



PROPOSED SUMP LAYOUT

SCALE 1:250

LEGEND

DESIGN

▨ ANNEX I HABITAT

LOUGH CORRIB cSAC BOUNDARY

TEMPORARY RETAINING ELEMENT OR SLOPE STABILITY MEASURES

1:2 SLOPE FROM BOTTOM OF APPROACH STRUCTURE TO GROUND LEVEL

SECANT PILE WALL

RC TROUGH WALL

NOTE:

1. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS NOTED OTHERWISE.
2. ALL LEVELS ARE SHOWN IN METERS ABOVE ORDNANCE DATUM.
3. FOR TYPICAL DETAILS SEE DRAWING GCOB-1700-D-S11-01-026.

Clients

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Galway County Council

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Job Title
N6 Galway City Ring Road

Scale 1:250 @ A1 / 1:500 @ A3

Date: February 2017

Issue	Date	By	Chkd	Appd
I2	14/09/2017	DC	PM	PM
I1	27/02/2017	DC	PM	PM

Drawing Title
Lackagh Tunnel & Western Approach
Western Approach
Proposed Sump Layout

Drawing Status
For Information

Job No **233985-00**
Drawing No **GCOB-1700-D-S11-01-027**
Issue **I2**

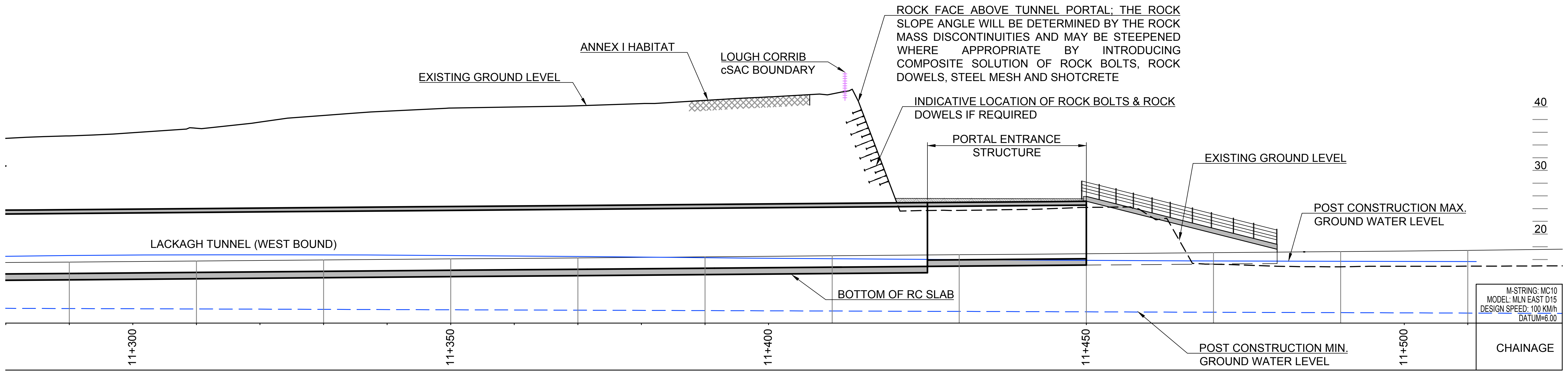
DESIGN REPORT

LEGEND

⊼	DESIGN
▨	ANNEX I HABITAT
┼┼┼┼	LOUGH CORRIB cSAC BOUNDARY
—o—	TEMPORARY RETAINING ELEMENT OR SLOPE STABILITY MEASURES
— · —	1:2 SLOPE FROM BOTTOM OF APPROACH STRUCTURE TO GROUND LEVEL
▥	SECANT PILE WALL
▬	RC TROUGH WALL

EASTERN APPROACH & TUNNEL PLAN

SCALE 1:500



EASTERN APPROACH & TUNNEL ELEVATION A-A

SCALE 1:500

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N6 Galway City Ring Road

Scale
1:500 @ A1 / 1:1000 @ A3

Date:
September 2017

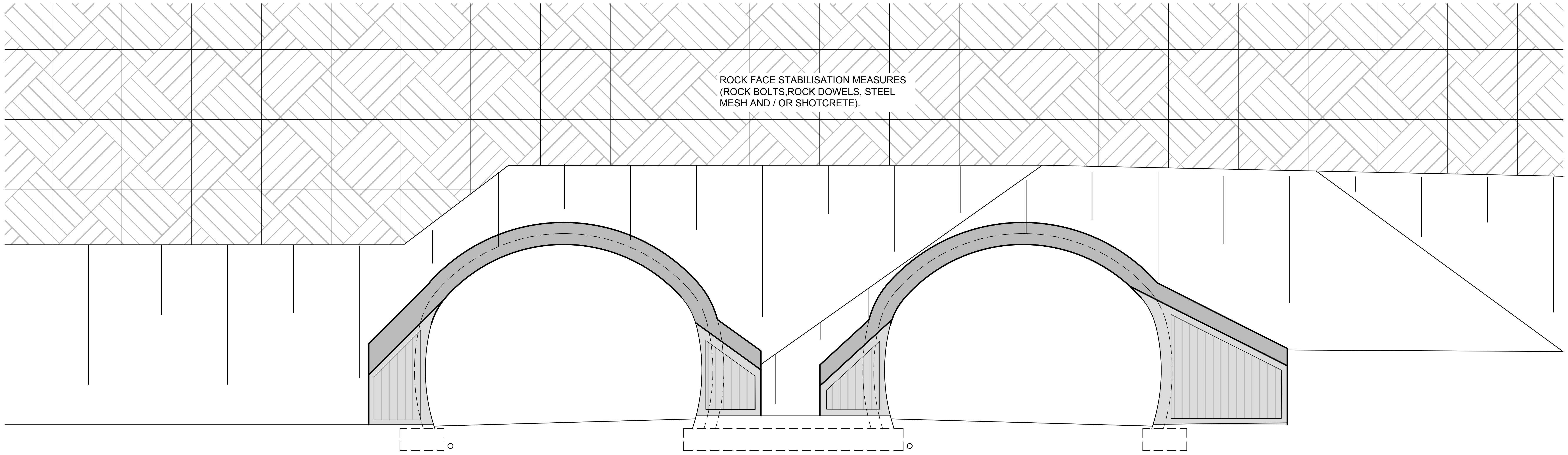
Issue	Date	By	Chkd	Appd
I1	14/09/2017	tp	PM	PM

Drawing Title
Lackagh Tunnel & Western Approach
Eastern Approach Plan & Elevation

Drawing Status
For Information

Job No	Drawing No	Issue
233985-00	**GCOB-1700-D-S11-01-030**	**I1**

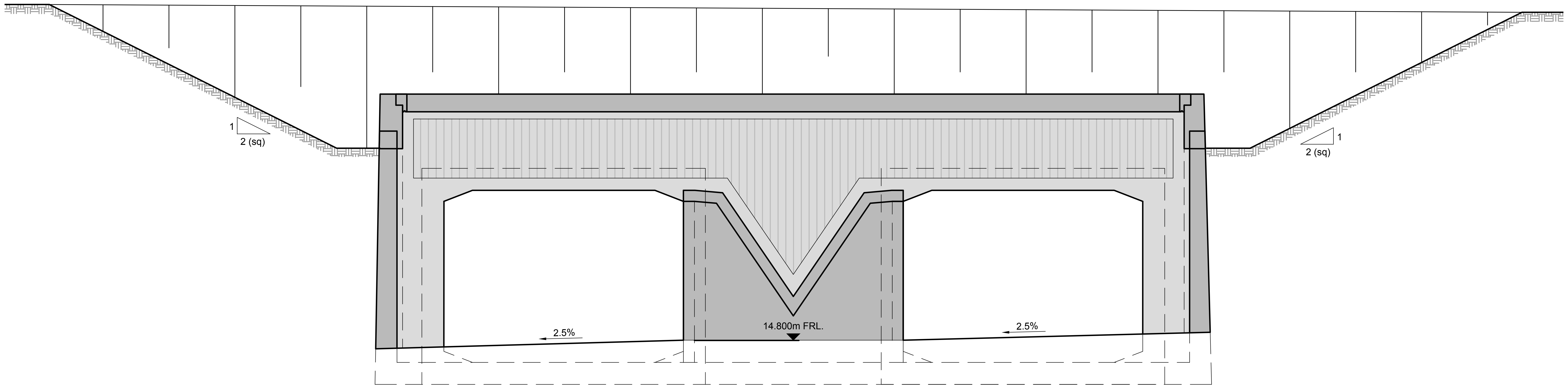
DESIGN REPORT



EASTERN PORTAL ELEVATION IN LACKAGH QUARRY

(CHAINAGE 11+450)
SCALE 1:125

NOTE
The aesthetic treatment of the portals will require further input from an aesthetic advisor and will be developed as the design progresses.



WEST PORTAL ELEVATION AT THE WESTERN APPROACH

(CHAINAGE 11+100)
SCALE 1:125

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Job Title
N6 Galway City Ring Road

Scale 1:500 @ A1 / 1:1000 @ A3
Date: September 2017

I1	14/09/2017	TP	PM	PM
Issue	Date	By	Chkd	Appd

Drawing Title
Lackagh Tunnel & Western Approach
Eastern Approach Plan & Elevation

Drawing Status
For Information

Job No	Drawing No	Issue
233985-00	**GCOB-1700-D-S11-01-040**	**I1**

Appendix B

Factual Site Investigation Data Drawings

R15-16

N6 Galway City Transport Project

Phase 3 Ground Investigation

Contract No. 2 - Factual Report

Galway County Council

Prepared by BRG Ltd. on behalf of Priority Drilling Ltd.

Dave Blaney

EXTRACT

Project Number:	**R15/16**
Author(s):	Dave Blaney P. Geo
BRG Ltd.	Galway County Council
Date of Report:	May 2016

R15/16
N6 Galway City Transport Project - Phase 3 Ground Investigation
Contract No. 2 - Factual Report
Dave Blaney P.Geo
May 2016

Contents

List of Figures

Appendices

NOT
INCLUDED IN
EXTRACT

1. Purpose and Scope of Works

Galway County Council, on its own behalf and on behalf of Galway City Council, are committed to developing a solution to the existing transportation issues in Galway City and its environs, which are having a negative impact upon the local, regional and national road network. As part of this work it is necessary to undertake ground investigation works prior to the commencement of detailed design work.

The Menlo region, within and to the immediate west of Lackagh Quarry, has been selected as a possible route for the N6 road development (Figure 1).

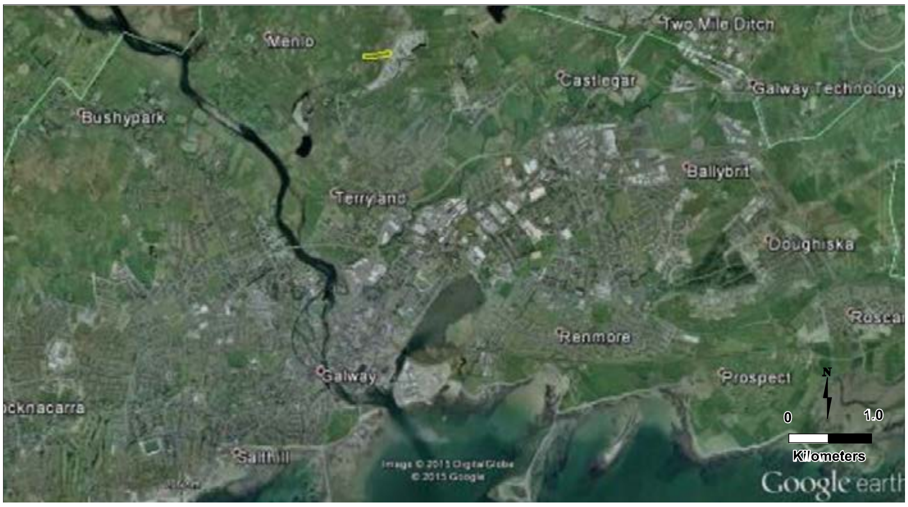

Figure 1: Lackagh Quarry Ground Investigation Site - Yellow Polygon (Google 2015)

The site consists of a non-active quarry with associated derelict buildings, plant, structures and poor quality agricultural land used for the grazing of cattle (Figure 2).

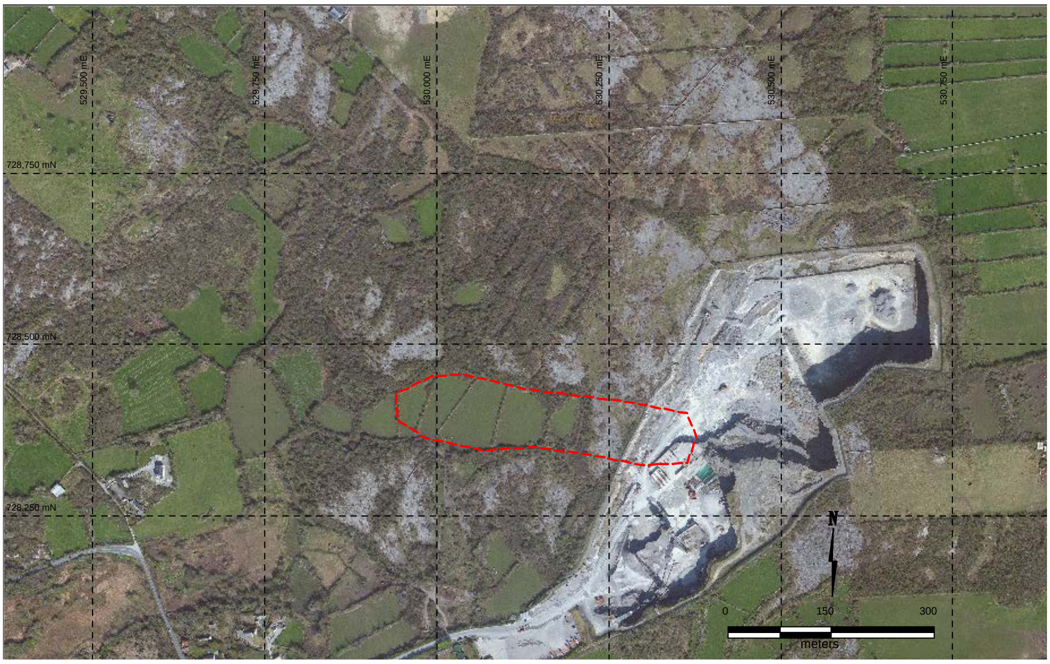

Figure 2: Site Area - Dashed Red Line

This area is in an environmentally sensitive region, with the Lough Corrib cSAC Annex 1 habitat (candidate Special Area of Conservation) located immediately west and north of the Lackagh Quarry site (Figure 3).

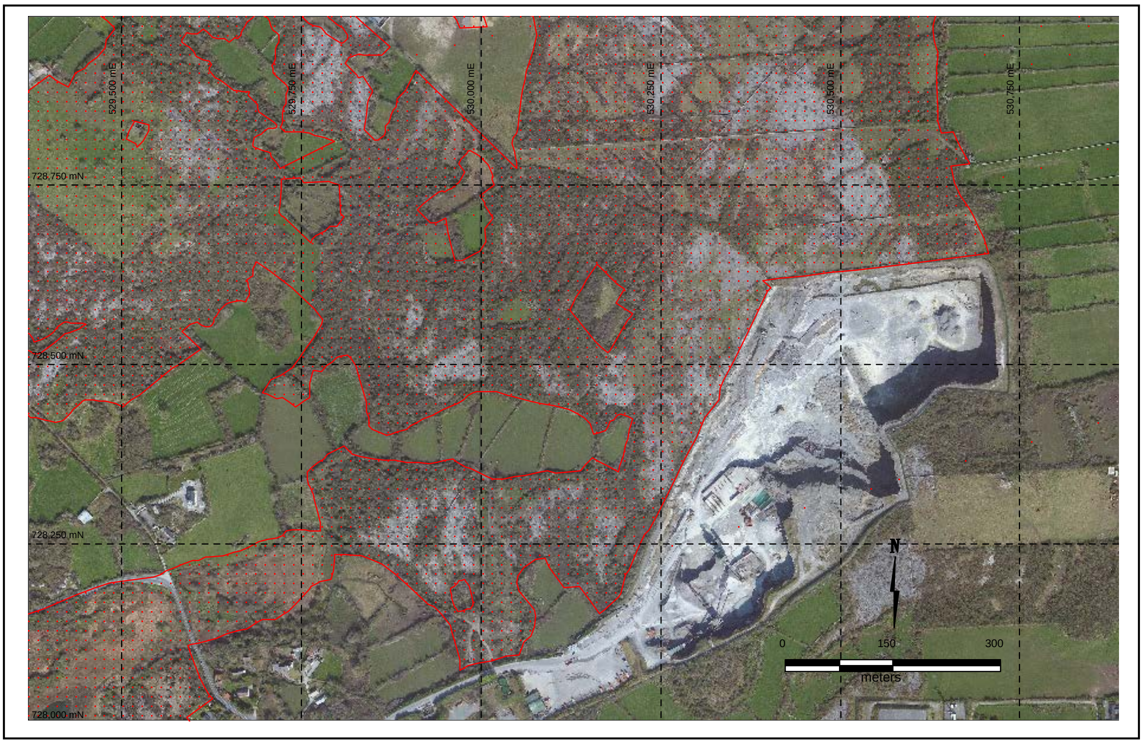

Figure 3: SAC Location (Red Hashed Area) (NPWS 2015)

The objective of the ground investigation is as follows:

- Characterise the nature of the rockmass for tunnel design;
- Characterise the hydrogeology for tunnel design and the existing groundwater conditions;
- Indentify any existing karst features and potential for karstic conditions with the rockmass
- Carryout in-situ and laboratory testing to provide geotechnical and hydrogeological parameters for tunnel design

In order to accomplish the stated objectives the following ground investigation was proposed:

- 1 No. Sub-horizontal rotary core drillhole along the proposed tunnel alignment for a length of approximately 300m
- 3 No. Vertical Rotary core drillholes to depths of 32.5m, 35.0m and 40.0m
- 3 No. Monitoring Installations (piezometers) with raised steel covers
- Geotechnical Laboratory Testing

- Downhole Geophysics
- Surface Geophysics
- Factual Reporting

2. Geological Setting and Ground Conditions

The site is underlain by Lower Carboniferous (Visean) Limestone located approximately 2km to the northeast of the contact with the Galway granitic intrusive complex (Figure 4). There is little published data for this region and Geological Survey of Ireland (GSI) 1:100,000 scale Bedrock Map series record this area as Undifferentiated Visean Shelf Limestones.

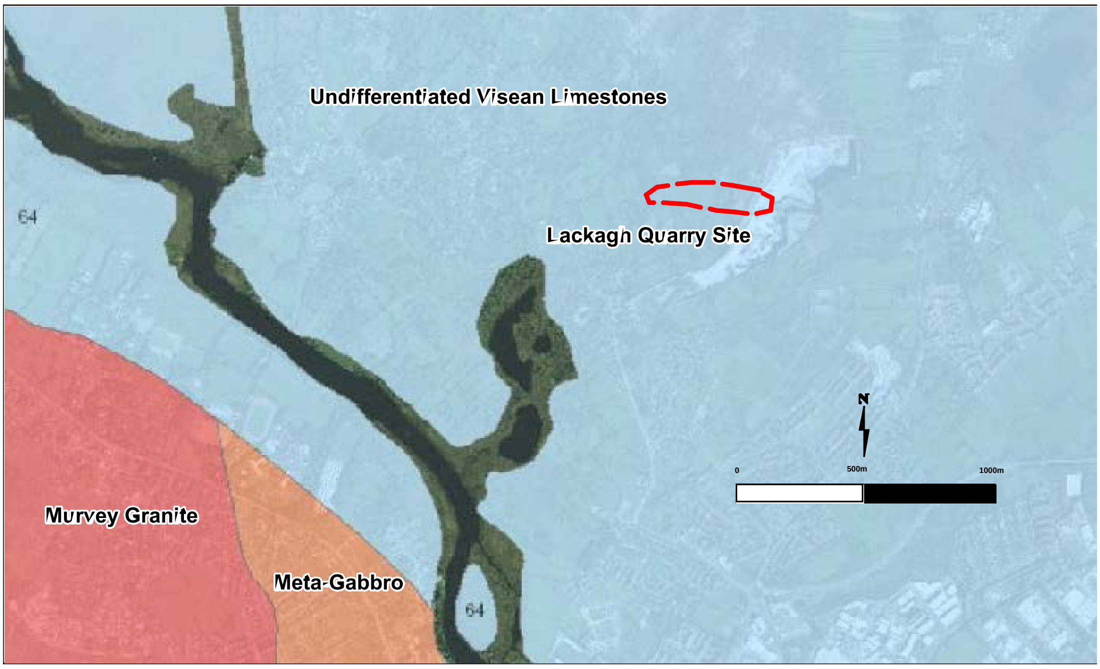

Figure 4: Simplified Geology Map of the Menlo Region (GSI 1:100,000 series)

The bedrock geology is dominated by light grey / grey, massively bedded, fine to medium grained pellety to weakly oolitic grainstones. Discrete, metric scale, beds of dark grey / black limestones are developed within the sequence. The black limestone beds are dominated by synsedimentary breccias with intraclastic clasts of grainstone supported in a black fine grained micritic matrix, this was only intersected by one of the ground investigation boreholes. There is evidence of burrowing and the brecciation may have been caused by bioturbation. Minor bioclastic debris is disseminated throughout, dominated by unrecognisable small shell fragments. Locally occurring coarse bioclastic fragments consist of thick shelled brachiopods and solitary corals. The fauna and well sorted nature of the rock are indicative of a shallow water, relatively high energy depositional environment. Thin (centimetric scale), horizons of grey / green to black mudstone form semi-continuous marker horizons within the geological sequence. The mudstone horizons (often known as clay wayboards) can be weakly tuffaceous, often containing a significant proportion of finely disseminated pyrite. The pyrite in these thin bands oxidises strongly and is responsible for the surficial iron staining present on parts of the lower benches at Lackagh Quarry.

The unconsolidated Quaternary geology of this region has been proven by the recent drilling to be much more complex than originally anticipated. A deep buried channel / trough is located to the west orientated along an east-west axis. Unconsolidated material deposited within this feature ranges from lacustrine, laminated (possibly varved) dark brown, organic clays to sands / gravels of a possibly fluviatile origin, all overlain by very stiff, glacial boulder clays.

Extensive areas of limestone pavement are developed to the north and west of the quarry site and there are numerous glacial erratics scattered throughout, many of which are granitic.

3. Ground Investigations

3.1 Setting Out / Surveying

Drawings and coordinates were provided by ARUP and were used to locate and position each borehole and geophysical station. The drillhole collar locations were positioned using a Trimble GeoExplorer 6000 RTK GPS system corrected to a differential base station through a phone modem link. Locations were measured relative to Irish Transverse Mercator.

The low angle borehole, BH01, was set out using the Trimble GeoExplorer 6000 RTK GPS system. The hole / working platform was orientated using a prismatic compass, accurate to +/- 0.5^o. The rig was then set up using a Reflex TN14 Gyrocompass to measure the exact dip and azimuth of the hole before coring commenced.

Downhole surveying of drillhole BH01 was carried out at 3m intervals using a Reflex EZ-TRAC digital downhole survey instrument. Owing to ground conditions (cavities and localised broken ground from 186m) the hole could only be surveyed from 175m back to surface. A core orientation tool had been used throughout the drilling that provided information about the dip of the hole, the driller noted no significant variation in dip from 175m. Refer to Appendix I for all surveying data.

3.2 Ground Geophysical Surveying

Ground geophysical surveying was specified for the Lackagh Quarry Ground Investigation. BRG Ltd were sub-contracted by Priority Drilling Ltd. to carry out the surveying. The geophysical surveys consisted of 2D Electrical Resistivity Tomography (ERT) and Microgravity across an initial area of roughly 300x30m, this area was subsequently extended to define the lateral and depth extent of a zone of deep overburden. The surveys were designed to test for subsurface heterogeneity and bedrock depths in advance of follow up rotary core drilling. Information on potential karst features were of particular interest to the client.

Microgravity data was acquired with measured sites along the centre line and 15m either side of the proposed tunnel section. These lines were measured with nominal station spacing of 10m, with gaps where scrub hawthorn was too thick. Extra stations were measured within the quarry on the first bench at 5-10m intervals. Measurements were taken using a Lacoste & Romberg model G gravity meter. Instrument drift was monitored by returning to a locally established base station at hourly intervals.

Stations were topographically surveyed using a Trimble GeoExplorer 6000 RTK GPS system corrected through phone modem link for both the ERT and the gravity surveys. The drift corrected gravity data was corrected for elevation, latitude, and reduced to Bouguer $2.67g/cm^3$ to allow for local average rock densities. It was then gridded and exported for display and interpretation in the MapInfo GIS system (Figure 5).

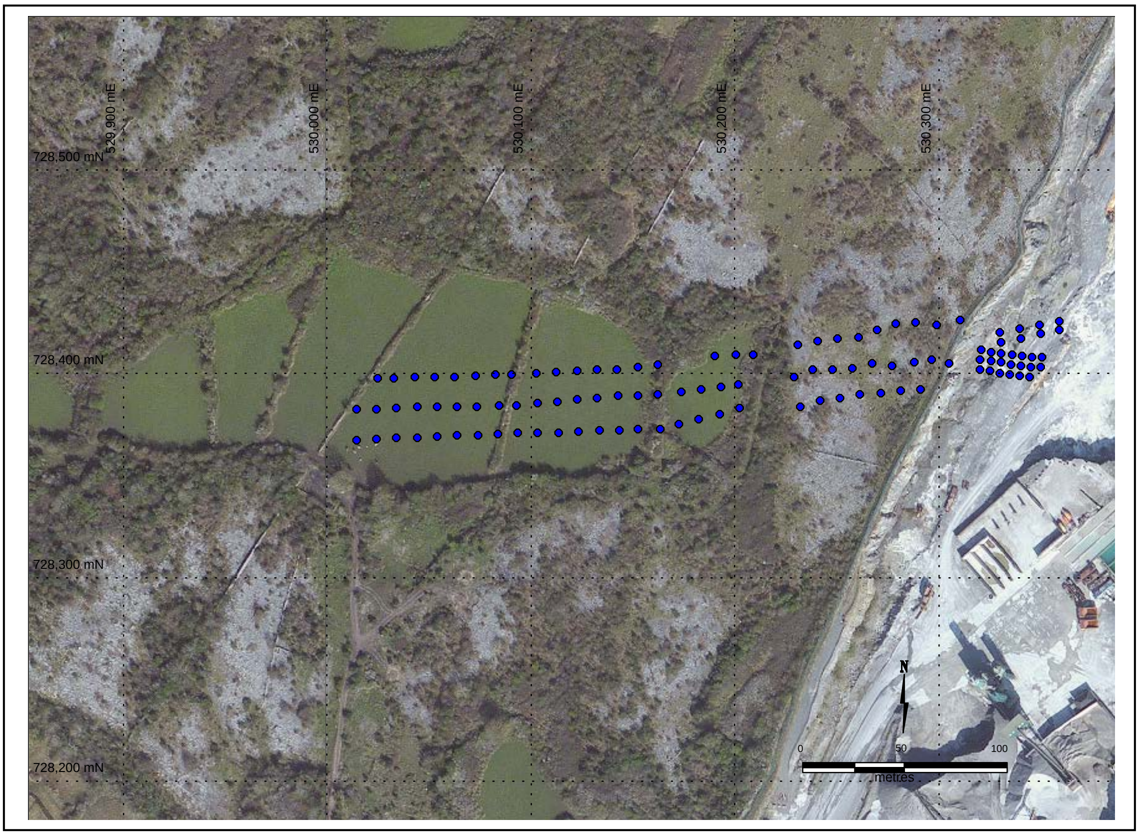

Figure 5: Microgravity Station Locations

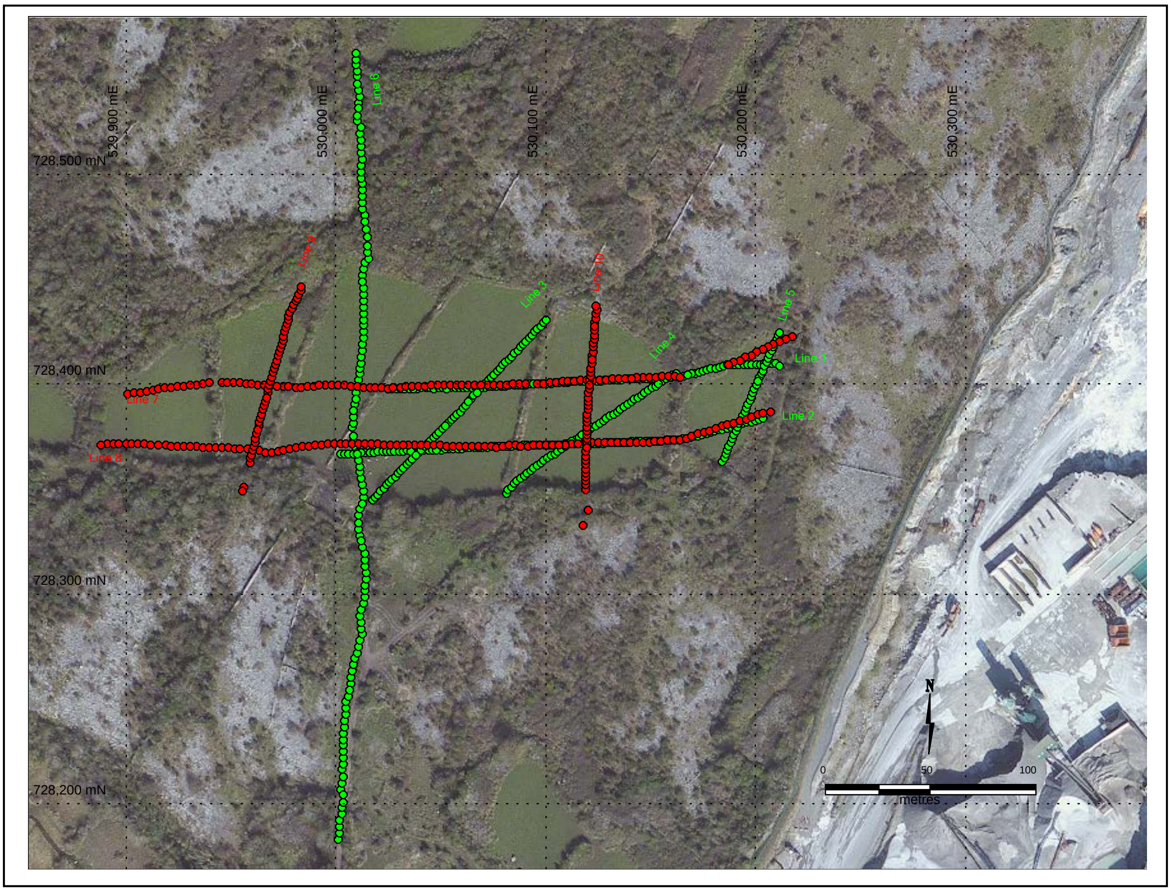

Figure 6: 2D Electrical Resistivity Tomography (ERT) Line / Station Locations

The depth mapping potential with the ERT is limited by the length of each spread. The variability of line lengths meant that the ERT surveying was capable of surveying to a minimum depth of 22m bgl on Line 5 to a maximum depth of 60m bgl on Line 6. Equipment used was an Allied Associates Tigre system which has the potential for up to 128 electrode takeouts. 2m station spacing was initially used to get the required detail along the chosen lines, with 3m intervals on the long lines (6, 7 & 8). Data was measured using a Wenner array, controlled by an Imager2006 programme with a laptop computer. Saved data was inverted using the Geotomo Res2Dinv programme and exported as an image file displaying a cross section of the inverted Resistivities with elevation data. The resultant resistivity sections were subsequently interpreted and an interpreted geological model developed.

Resistivity sections from the 2D ERT and the microgravity data show a marked contrast from high resistivity bedrock in the east with a sharp contact into very low resistivity zones to the west. The western region has a low gravity response coincident with the low resistivity. The base of the initial ERT lines did not penetrate below 30m, however, the low resistivity zone developed to the west suggests that this area was dominated by a significant deep overburden feature. Subsequent 2D ERT surveying, particularly line 6 defined a channel / basin shaped feature developed along a roughly east - west axis with sharp contacts to the north and south. The northern side of the feature seems to be step down into the core of the channel, which is roughly coincident with BH03. The surface geophysical report is appended as Appendix V.

3.3 Rotary Borehole Investigation

Five rotary boreholes were drilled during this phase of the investigation. Four vertical and one low angle borehole drilled from the quarry floor (Figures 5 & 6).

DHID	East	North	Elevation	Dip	Azimuth	Length (m)
BH01	530370.592	728426.557	16.712	-11.5°	268.3°	276.7
BH03	530023.824	728382.566	26.256	-90°	360°	109.9
BH04	530150.783	728400.125	32.167	-90°	360°	35
BH05	530186.649	728378.105	34.138	-90°	360°	40.3
BH06	530125.143	728383.081	30.799	-90°	360°	45

Table 1: Borehole Collar Locations

3.3.1 Low Angle Drilling (HQ Core)

The low angle borehole, BH01, was drilled using a Dura Lite rig producing HQ diameter core (63.5mm). This borehole was drilled using a 3m hexagonal core barrel in order to minimise droop and deflection away from the planned section. The borehole was collared at an azimuth of 268.3° N_{mag} and a dip of -11.5° to the horizontal. BH01 was located within the boundary of the quarry and was designed to drill into the quarry face. The hole was located at the base of the lower bench and rig was stepped back approximately 6m from the quarry face. The face was scaled back before the rig was moved onto site using an excavator to remove loose, unstable rock material that was at risk of collapse. A concrete plinth was constructed between the borehole collar and the quarry face to support the rods whilst drilling and accordingly the first 6m cored from BH01 consists of concrete.

BH01 was drilled to a final depth of 276.7m. It was scheduled to drill to approximately 300m. However, poor quality and unconsolidated / cavernous ground intersected from 272.4m to the end of hole at 276.7m meant that the hole could not be continued.

After drilling was completed borehole BH01 was sealed at a depth of 175m using a Vann Ruth plug and was then backfilled with a cement / bentonite grout from 175m back to surface. The cavities in the lower part of the hole (175.0 - 276.7m) contributed to localised unstable ground conditions and it was considered a significant possibility that they may act as conduits to draw the cement / bentonite grout away from the hole, therefore, a plug was installed at 175m to seal the lower part of the hole.

3.3.2 Vertical Drilling (PQ Core)

The vertical boreholes (BH03, BH04, BH05 & BH06) were all drilled using a top drive Hang Seng drilling rig producing PQ diameter drill core (85mm). The holes were collared along the line of the proposed tunnel route to the west of the quarry. BH03 was scheduled to drill to a depth of 32.5m, however, it drilled through a deep overburden feature with very challenging, poorly consolidated ground, intersecting rock at a depth of 104.95m and stopping at a depth of 109.9m. The hole was cored to 85.55m in PQ and subsequently cased to 85m with PW casing. It was then open hole drilled using a HQ tricone until competent ground was intersected at 104.95m and continued to the end of hole with HQ core. Due to the instability of hole BH03 the planned piezometer could not be installed or the downhole geophysical survey carried out. It was backfilled with a cement / bentonite grout upon completion.

BH04 and BH05 were drilled to scheduled depths and intersected the expected geological succession of shallow overburden overlying competent, massively bedded limestones. Piezometers were installed in both of these holes. BH06 was an additional hole added to the ground investigation to test a zone of transition from competent to poorly consolidated rock / overburden that had been detected by the ground geophysical survey. This hole was drilled to a final depth of 45m in unconsolidated clay, sand and gravel it was backfilled with a cement grout from the end of hole back to a depth of 11.0m. A stand pipe was installed in the top of the hole.

The core from the rotary drilling was logged in accordance with the BS5930:1999 specification. A detailed geological description of the rock was generated and a quantitative description of the fracture state of the rock core was provided for each borehole, including:

- Total Core Recovery (TCR)
- Solid Core Recovery (SCR)
- Fracture Index (FI)
- Fracture Number (FNo.)
- Rock Quality Designation (RQD)

The logs were generated using HoleBase AGS software (Hard copies - Appendix II).

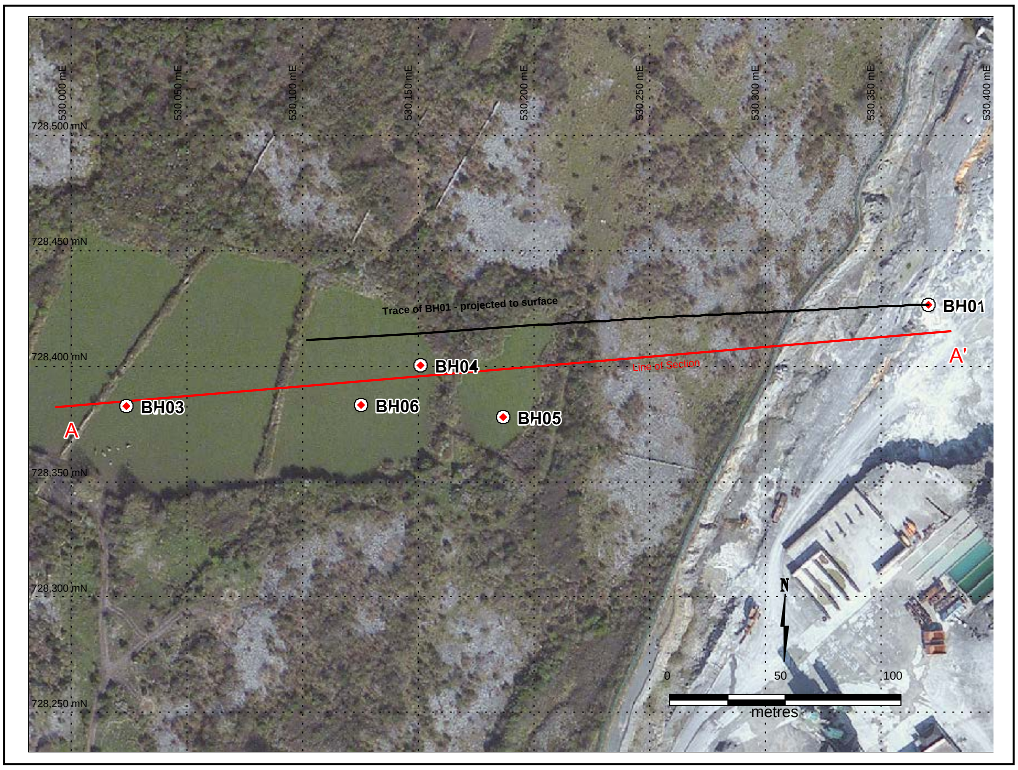

Figure 7: Borehole Collar Locations, Traces and Line of Section

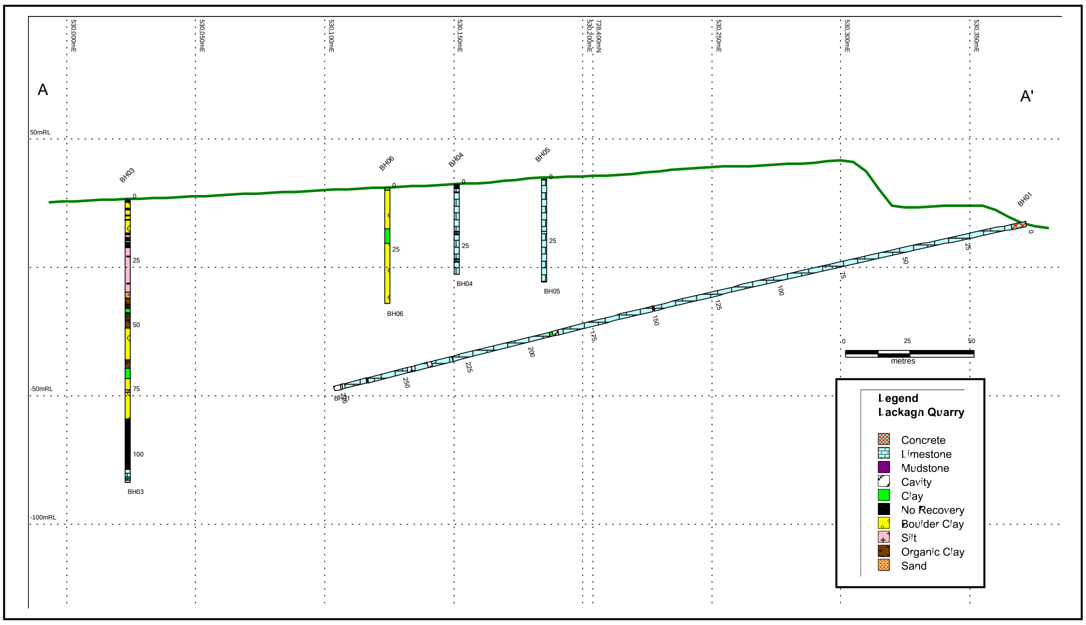

Figure 8: A - A' Drill Section (looking North) through the Lackagh Quarry GI Site

3.4 Discontinuity Logging

Discontinuity logging of rock cores was carried out using the ARUP "Rock Core Discontinuity Log" template for holes BH01, BH04 and BH05. The following headings were used:

- Orientation
- Spacing
- Roughness
- Weathering
- Infilling
- Number of Discontinuity Sets

The core from BH01 was orientated using a core orientation system mounted on the core barrel. and the discontinuities were measured relative to the invert of the core (NB: downhole direction is 180^o up hole is 0^o).

See Appendix III for the discontinuity logs.

3.5 Piezometer Installations

Three piezometers were installed in the vertical boreholes located to the west of the quarry. They were installed in boreholes BH04, BH05 and BH06. A summary of the installation design can be seen in Tables 2 - 4.

From (m)	To (m)	Installation
0.00	28.00	Blank 19mm PVC Pipe
28.00	34.00	Slotted 19mm PVC Pipe
34.00		End Cap
0.00	21.00	Cement Grout
21.00	23.00	Bentonite Pellets
23.00	24.00	Sand
24.00	34.00	Pea Gravel
34.00	35.00	Gravel Base

Table 2: BH04 Piezometer Installation Details

From (m)	To (m)	Installation
0.00	33.00	Blank 19mm PVC Pipe
33.00	39.00	Slotted 19mm PVC Pipe
39.00		End Cap
0.00	19.00	Cement Grout
19.00	23.00	Bentonite Pellets
23.00	24.00	Sand
24.00	39.00	Pea Gravel
39.00	40.30	Gravel Base

Table 3: BH05 Piezometer Installation Details

From (m)	To (m)	Installation
0.00	4.00	Blank 19mm PVC Pipe
4.00	10.00	Slotted 19mm PVC Pipe
10.00		End Cap
0.00	1.00	Cement Grout
1.00	2.00	Bentonite Pellets
2.00	3.00	Sand
3.00	11.00	Pea Gravel
11.00	45.00	Cement Grout

Table 4: BH06 Piezometer Installation Details

3.6 Borehole Geophysical Surveying

Ground geophysical surveying was specified for the Lackagh Quarry Ground Investigation. European Geophysical Services Ltd were sub-contracted by Priority Drilling Ltd. to carry out this surveying. It was originally intended to survey three boreholes, however, the poor ground conditions encountered in BH03 meant that only BH04 and BH05 were surveyed.

The geophysical surveys consisted of:

- Optical Televiewer
- Acoustic Televiewer
- Fluid Temperature and Conductivity, Natural Gamma Calliper
- Impeller Flowmeter
- Focused Resistivity
- Full Wave Sonic Velocity
- Pumped Temperature and Conductivity

Report attached as Appendix VI

3.7 Rock / Soil / Water - Laboratory Testing

Core samples were taken from the rock / soil recovered during the drilling operations and forwarded to two accredited laboratories for a testing. The Celtest Laboratory near Bangor in North Wales was selected to carry out the rock testing. The Priority Geotechnical Soil testing Laboratory was selected to carry out the soil testing.

Test	BH01 (No.)	BH04 (No.)	BH05 (No.)	Total Number of Tests
Deformability in Uniaxial Compression	10	5	5	20
Indirect Tensile Strength by Brazilian Test	3	1	1	5
Natural Water Content	40	10	9	59
Oxidisable Sulphate	5	1	1	7
pH Value	5	1	1	7
Point Load	58	25	25	108
Porosity / Density using Saturation & Buoyancy	15	2	3	20
Porosity / Density using Saturation & Calliper	15	2	3	20
Thin Section Petrography	2	1	1	4
Total Sulphur	6	1	1	8
Uniaxial Compressive Strength	36	10	10	56
Total	**195**	**59**	**60**	**314**

Table 5: Scheduled Rock Tests

Test	BH03 (No.)	BH06 (No.)	Total Number of Tests
Atterberg Limits	9	3	12
Moisture Content	19	3	22
Oedometer	4	3	7
Organic Matter Content	9	3	12
Particle Size Distribution	9	0	9
pH Value	5	0	5
Triaxial Test (Unconsolidated / Undrained)	5	3	8
Total	**60**	**15**	**75**

Table 6: Scheduled Soil Tests

A suite of aggregate tests had been scheduled in the Bill of Quantities, including:

- Slake Durability Index
- Los Angeles Coefficient
- Aggregate Crushing Value
- Ten Percent Fines
- Aggregate Impact Value
- Aggregate Abrasion Value
- Polished Stone Value
- Aggregate Frost Heave

The volume of material required to carry out these tests was excessive (e.g. the Aggregate Frost Heave test needs a minimum of 75kg of rock) and would have taken the bulk of the available drill core. Given the relatively homogenous nature of the limestone intersected it was agreed that a representative bulk sample would be acquired from the quarry and sent for the specified aggregate testing. Accordingly, a composite, 275kg, representative sample was obtained from the quarry and sent to Celtest.

Water samples were obtained from the piezometers in boreholes BH04, BH05 and BH06 and sent to the IAS Laboratory in Bagenalstown, Co Carlow for testing for major cations and anions.

Test results are summarised in Tables 7 - 10 certificates are attached as Appendix VII

Location ID	Sample ID	Depth Top	Depth Base	Test	Result
BH01	**48861**	6.70	6.80	Moisture Content	**1.20%**
BH01	**48862**	10.36	10.46	Point Load	**79.3MPa**
BH01	**48863**	10.46	10.69	Uniaxial Compressive Strength	**97MPa**
BH01	**48864**	10.69	10.76	Point Load	**78MPa**
BH01	**48865**	10.89	10.97	Porosity / Density using Saturation and Buoyancy	**0.5 / 2.63**
BH01	**48866**	10.97	11.07	Porosity / Density using Saturation and Calliper	**0.47/2.69**
BH01	**48867**	11.57	11.94	Deformability in Uniaxial Compression	**99.8MPa**
BH01	**48868**	13.26	13.35	Moisture Content	**1.60%**
BH01	**48869**	13.35	13.45	Point Load	**82.9MPa**
BH01	**48870**	13.45	13.70	Uniaxial Compressive Strength	**59MPa**
BH01	**48871**	13.70	13.80	Point Load	**71.9MPa**
BH01	**48872**	16.30	16.40	Point Load	**67.7MPa**
BH01	**48873**	16.40	16.66	Uniaxial Compressive Strength	**73MPa**
BH01	**48874**	16.66	16.80	Point Load	**76.5MPa**
BH01	**48875**	22.40	22.50	Porosity / Density using Saturation and Calliper	**0.58/2.65**
BH01	**48876**	22.50	22.60	Porosity / Density using Saturation and Buoyancy	**1.2 / 2.70**
BH01	**48877**	26.20	26.36	Point Load	**47.1MPa**
BH01	**48878**	26.36	26.61	Uniaxial Compressive Strength	**100MPa**
BH01	**48879**	26.61	26.70	Point Load	**60.5MPa**
BH01	**48880**	27.85	28.15	Deformability in Uniaxial Compression	**112.4MPa**
BH01	**48881**	32.65	32.72	Moisture Content	**1.40%**
BH01	**48882**	34.44	34.48	Point Load	**88.8MPa**
BH01	**48883**	34.48	34.73	Uniaxial Compressive Strength	**69MPa**
BH01	**48884**	34.73	34.83	Point Load	**62.2MPa**
BH01	**48885**	44.35	44.40	Porosity / Density using Saturation and Calliper	**0.54/2.70**
BH01	**48886**	44.45	44.54	Point Load	**84.8MPa**
BH01	**48887**	44.54	44.79	Uniaxial Compressive Strength	**83MPa**
BH01	**48888**	44.79	44.90	Point Load	**53.0MPa**

BH01	**48889**	45.65	45.74	Porosity / Density using Saturation and Buoyancy	**0.5/2.68**
BH01	**48890**	48.90	49.16	Deformability in Uniaxial Compression	**187.5MPa**
BH01	**48891**	53.80	53.93	Total Sulphur	**<0.1%**
BH01	**48892**	55.30	55.40	Oxidisable Sulphate	**<0.01%**
BH01	**48893**	55.84	55.92	pH Value	**9.1**
BH01	**48894**	56.50	56.60	Point Load	**64.4MPa**
BH01	**48895**	56.60	56.85	Uniaxial Compressive Strength	**138MPa**
BH01	**48896**	56.85	56.93	Point Load	**63.9MPa**
BH01	**48897**	57.30	57.40	Moisture Content	**1.10%**
BH01	**48898**	61.65	61.75	Moisture Content	**1.20%**
BH01	**48899**	62.76	62.86	Point Load	**83.4MPa**
BH01	**48900**	62.86	63.05	Uniaxial Compressive Strength	**65MPa**
BH01	**50857**	63.05	63.16	Point Load	**49.6MPa**
BH01	**50858**	64.20	64.50	Indirect Tensile Strength by Brazilian Test	**7.8MPa**
BH01	**50859**	65.40	65.50	Total Sulphur	**<0.1%**
BH01	**50860**	65.66	65.75	Porosity / Density using Saturation and Buoyancy	**0.2/2.72**
BH01	**50861**	65.75	65.92	Porosity / Density using Saturation and Calliper	**0.64/2.69**
BH01	**50862**	66.00	66.10	Point Load	**69.6MPa**
BH01	**50863**	66.10	66.34	Uniaxial Compressive Strength	**104MPa**
BH01	**50864**	66.34	66.45	Point Load	**62.6MPa**
BH01	**50865**	67.07	67.20	Moisture Content	**1.10%**
BH01	**50866**	67.20	67.28	Porosity / Density using Saturation and Calliper	**0.57/2.71**
BH01	**50867**	68.50	68.59	Porosity / Density using Saturation and Buoyancy	**0.2/2.63**
BH01	**50868**	70.10	70.20	Moisture Content	**1.30%**
BH01	**50869**	72.10	72.30	Deformability in Uniaxial Compression	**136.3MPa**
BH01	**50870**	73.03	73.10	Moisture Content	**1.60%**
BH01	**50871**	76.00	76.09	Moisture Content	**1.20%**
BH01	**50872**	79.10	79.18	Point Load	**51.8MPa**
BH01	**50873**	79.18	79.40	Uniaxial Compressive Strength	**62MPa**
BH01	**50874**	79.40	79.52	Point Load	**48.0MPa**
BH01	**50875**	80.04	80.12	Moisture Content	**1.20%**
BH01	**50876**	81.70	81.78	Moisture Content	**1.60%**
BH01	**50877**	87.50	87.57	Moisture Content	**1.80%**
BH01	**50878**	39.70	39.80	Moisture Content	**1.30%**
BH01	**50879**	91.10	91.20	Total Sulphur	**<0.1%**
BH01	**50880**	91.34	91.42	Porosity / Density using Saturation and Calliper	**0.49/2.71**
BH01	**50881**	91.42	91.51	Porosity / Density using Saturation and Buoyancy	**1.0/2.70**
BH01	**50882**	91.63	91.71	Moisture Content	**1.80%**
BH01	**50883**	92.35	92.47	Point Load	**73.3MPa**
BH01	**50884**	92.47	92.70	Uniaxial Compressive Strength	**76MPa**

BH01	**50885**	92.70	92.79	Point Load	**71.1**
BH01	**50886**	93.00	93.10	Moisture Content	**1.50%**
BH01	**50887**	94.90	94.96	Oxidisable Sulphate	**<0.01%**
BH01	**50888**	94.96	95.05	pH Value	**9.2**
BH01	**50889**	97.34	97.43	Moisture Content	**1.30%**
BH01	**50890**	97.95	98.23	Deformability in Uniaxial Compression	**110.0MPa**
BH01	**50891**	101.36	101.45	Moisture Content	**1.60%**
BH01	**50892**	102.90	103.20	Indirect Tensile Strength by Brazilian Test	**12.6MPa**
BH01	**50893**	108.15	108.22	Point Load	**61.2MPa**
BH01	**50894**	108.22	108.51	Uniaxial Compressive Strength	**107MPa**
BH01	**50895**	108.51	108.62	Point Load	**70.2MPa**
BH01	**50896**	108.62	108.70	Moisture Content	**1.20%**
BH01	**50897**	110.27	110.37	Porosity / Density using Saturation and Calliper	**0.57/2.69**
BH01	**50898**	110.37	110.45	Porosity / Density using Saturation and Buoyancy	**0.7/2.59**
BH01	**50899**	113.00	113.08	Thin Section - Petrology	
BH01	**50900**	113.12	113.19	Moisture Content	**1.50%**
BH01	**50901**	115.89	116.05	Point Load	**52.5MPa**
BH01	**50902**	116.05	116.29	Uniaxial Compressive Strength	**104MPa**
BH01	**50903**	116.29	116.39	Point Load	**62.2MPa**
BH01	**50904**	118.82	118.88	Moisture Content	**1.90%**
BH01	**50905**	123.44	123.55	Moisture Content	**2.20%**
BH01	**50906**	125.90	126.00	Moisture Content	**1.30%**
BH01	**50907**	126.80	126.90	Moisture Content	**2.50%**
BH01	**50908**	128.80	128.89	Point Load	**80.8MPa**
BH01	**50909**	128.89	129.14	Uniaxial Compressive Strength	**79MPa**
BH01	**50910**	129.14	129.21	Point Load	**84.0MPa**
BH01	**50911**	131.12	131.17	Moisture Content	**2.60%**
BH01	**50912**	131.60	131.70	Moisture Content	**1.20%**
BH01	**50913**	132.65	132.62	Moisture Content	**1.80%**
BH01	**50914**	133.21	133.32	Point Load	**69.2MPa**
BH01	**50915**	133.32	133.54	Uniaxial Compressive Strength	**110MPa**
BH01	**50916**	133.54	133.63	Point Load	**61.8MPa**
BH01	**50917**	134.35	134.44	Moisture Content	**1.10%**
BH01	**50918**	137.06	137.20	Porosity / Density using Saturation and Calliper	**0.76/2.81**
BH01	**50919**	37.20	137.30	Porosity / Density using Saturation and Buoyancy	**0.3/2.63**
BH01	**50920**	138.60	138.72	pH Value	**9.2**
BH01	**50921**	140.00	140.20	Deformability in Uniaxial Compression	**58.7MPa**
BH01	**50922**	142.81	142.91	Moisture Content	**1.30%**
BH01	**50923**	146.20	146.30	Point Load	**55.0MPa**
BH01	**50924**	146.30	146.52	Uniaxial Compressive Strength	**100MPa**
BH01	**50925**	146.52	146.61	Point Load	**62.6MPa**
BH01	**50926**	148.97	149.05	Thin Section - Petrology	

BH01	**50927**	150.29	150.37	Porosity / Density using Saturation and Calliper	**0.61/2.75**
BH01	**50928**	151.67	151.75	Porosity / Density using Saturation and Buoyancy	**0.7/2.67**
BH01	**50929**	152.97	153.04	Total Sulphur	**<0.1%**
BH01	**50930**	153.20	153.30	Oxidisable Sulphate	**<0.01%**
BH01	**50931**	154.60	154.68	Moisture Content	**1.40%**
BH01	**50932**	155.20	155.28	Moisture Content	**1.70%**
BH01	**50933**	156.33	156.44	Point Load	**42.0MPa**
BH01	**50934**	156.44	156.68	Uniaxial Compressive Strength	**86MPa**
BH01	**50935**	156.68	156.76	Point Load	**47.3MPa**
BH01	**50936**	163.49	163.56	Moisture Content	**2.50%**
BH01	**50937**	165.17	165.25	Point Load	**77.7MPa**
BH01	**50938**	165.25	165.49	Uniaxial Compressive Strength	**83MPa**
BH01	**50939**	165.49	165.58	Point Load	**64.6MPa**
BH01	**50940**	166.00	166.10	Moisture Content	**1.30%**
BH01	**50941**	172.96	173.07	Porosity / Density using Saturation and Calliper	**0.49/2.68**
BH01	**50942**	173.07	173.20	Porosity / Density using Saturation and Buoyancy	**0.4/2.72**
BH01	**50943**	174.47	174.69	Uniaxial Compressive Strength	**76MPa**
BH01	**50944**	175.18	175.26	Point Load	**58.6MPa**
BH01	**50945**	175.26	175.50	Uniaxial Compressive Strength	**86MPa**
BH01	**50946**	175.50	175.59	Point Load	**58.6MPa**
BH01	**50947**	176.00	176.10	Moisture Content	**1.20%**
BH01	**50948**	180.24	180.50	Indirect Tensile Strength by Brazilian Test	**14.6MPa**
BH01	**50949**	182.12	182.20	pH Value	**9.3**
BH01	**50950**	183.17	183.40	Deformability in Uniaxial Compression	**118.6MPa**
BH01	**50951**	183.90	184.02	Point Load	**48.8MPa**
BH01	**50952**	184.02	184.25	Uniaxial Compressive Strength	**97MPa**
BH01	**50953**	184.25	184.34	Point Load	**70.1MPa**
BH01	**50954**	196.19	186.25	Moisture Content	**1.80%**
BH01	**50955**	193.60	193.68	Total Sulphur	**<0.1%**
BH01	**50956**	194.13	194.20	Porosity / Density using Saturation and Calliper	**0.54/2.69**
BH01	**50957**	194.60	194.67	Point Load	**48.0MPa**
BH01	**50958**	194.67	194.90	Uniaxial Compressive Strength	**114MPa**
BH01	**50959**	194.90	194.99	Point Load	**57.6MPa**
BH01	**50960**	195.77	195.86	Porosity / Density using Saturation and Buoyancy	**0.5/2.71**
BH01	**50961**	201.47	201.55	Oxidisable Sulphate	**<0.01%**
BH01	**50962**	204.62	204.70	Point Load	**83.6MPa**
BH01	**50963**	204.70	204.95	Uniaxial Compressive Strength	**132MPa**
BH01	**50964**	204.95	205.02	Point Load	**60.5**
BH01	**50965**	209.65	209.72	Moisture Content	**1.70%**
BH01	**50966**	210.18	210.30	Porosity / Density using Saturation and Calliper	**0.65/2.69**

BH01	**50967**	210.30	210.40	Porosity / Density using Saturation and Buoyancy	**0.3/2.85**
BH01	**50968**	210.57	210.82	Uniaxial Compressive Strength	**111MPa**
BH01	**50969**	211.10	211.20	Moisture Content	**1.40%**
BH01	**50970**	211.77	211.85	Point Load	**56.2MPa**
BH01	**50971**	211.85	212.10	Uniaxial Compressive Strength	**52MPa**
BH01	**50972**	212.10	212.20	Point Load	**68.7MPa**
BH01	**50973**	212.33	212.58	Deformability in Uniaxial Compression	**104.7MPa**
BH01	**50974**	213.80	213.90	pH Value	**9.1**
BH01	**50975**	218.20	218.28	Moisture Content	**1.50%**
BH01	**50976**	222.52	222.62	Moisture Content	**1.00%**
BH01	**50977**	223.70	223.80	Porosity / Density using Saturation and Calliper	**0.56/2.75**
BH01	**50978**	224.08	224.20	Porosity / Density using Saturation and Buoyancy	**0.3/2.63**
BH01	**50979**	225.65	225.74	Point Load	**80.3MPa**
BH01	**50980**	225.74	225.95	Uniaxial Compressive Strength	**77MPa**
BH01	**50981**	225.95	226.03	Point Load	**72.3MPa**
BH01	**50982**	228.16	228.24	Porosity / Density using Saturation and Calliper	**0.64/2.70**
BH01	**50983**	228.24	228.32	Porosity / Density using Saturation and Buoyancy	**0.4/2.65**
BH01	**50984**	230.13	230.20	Moisture Content	**2.00%**
BH01	**50985**	231.65	231.78	Point Load	**53.0MPa**
BH01	**50986**	231.78	232.00	Uniaxial Compressive Strength	**111MPa**
BH01	**50987**	232.00	232.10	Point Load	**74.6MPa**
BH01	**50988**	232.46	232.60	Deformability in Uniaxial Compression	**69.6MPa**
BH01	**50989**	235.04	235.10	Moisture Content	**1.30%**
BH01	**50990**	235.64	235.73	Total Sulphur	**<0.1%**
BH01	**50991**	236.73	237.03	Uniaxial Compressive Strength	**80MPa**
BH01	**50992**	237.17	237.43	Uniaxial Compressive Strength	**76MPa**
BH01	**50993**	242.82	242.92	Point Load	**53.8MPa**
BH01	**50994**	242.92	243.14	Uniaxial Compressive Strength	**118MPa**
BH01	**50995**	243.14	243.23	Point Load	**64.6MPa**
BH01	**50996**	250.30	250.56	Deformability in Uniaxial Compression	**56.4MPa**
BH01	**50997**	251.81	251.95	Point Load	**52.5MPa**
BH01	**50998**	251.95	252.22	Uniaxial Compressive Strength	**121MPa**
BH01	**50999**	252.22	252.32	Point Load	**61.4MPa**
BH01	**51000**	253.30	253.38	Oxidisable Sulphate	**<0.01%**
BH01	**51001**	259.72	259.82	Point Load	**64.1MPa**
BH01	**51002**	259.82	260.06	Uniaxial Compressive Strength	**143MPa**
BH01	**51003**	260.06	260.18	Point Load	**44.9MPa**
BH01	**51004**	262.43	262.63	Uniaxial Compressive Strength	**66MPa**
BH01	**51005**	262.63	262.73	Point Load	**67.7MPa**
BH01	**51006**	264.80	164.93	Point Load	**48.5MPa**
BH01	**51007**	264.93	264.15	Uniaxial Compressive Strength	**83MPa**
BH01	**51008**	265.15	265.25	Porosity / Density using Saturation and Calliper	**0.63/2.65**

BH01	**51009**	265.25	265.38	Porosity / Density using Saturation and Buoyancy	**0.5/2.64**
BH01	**51010**	268.30	268.40	Uniaxial Compressive Strength	**90MPa**
BH01	**51011**	271.70	271.90	Uniaxial Compressive Strength	**91MPa**

Table 7: Summary of Rock Test Results in BH01.

Location ID	**Sample ID**	**Depth Top**	**Depth Base**	**Test**	**Certificate**
BH03	**48801**	4.15	4.42	Triaxial - Unconsolidated / Undrained	x
BH03	**48802**	13.65	13.73	Moisture Content	x
BH03	**48803**	13.73	13.85	Atterberg Limits	x
BH03	**48804**	14.90	15.00	Particle Size Distribution	x
BH03	**48805**	19.00	19.10	Particle Size Distribution	x
BH03	**48806**	19.10	19.20	Atterberg Limits	x
BH03	**48807**	19.25	19.30	Moisture Content	x
BH03	**48808**	19.90	20.00	Moisture Content	x
BH03	**48809**	20.95	21.05	pH	x
BH03	**48810**	21.30	21.40	Moisture Content	x
BH03	**48811**	25.50	25.60	Particle Size Distribution	x
BH03	**48812**	25.80	25.90	Particle Size Distribution	x
BH03	**48813**	26.50	26.60	Particle Size Distribution	x
BH03	**48814**	26.70	26.80	Particle Size Distribution	x
BH03	**48815**	27.20	27.25	pH	x
BH03	**48816**	27.45	27.55	Atterberg Limits	x
BH03	**48817**	27.55	27.65	Particle Size Distribution	x
BH03	**48818**	30.25	30.33	Particle Size Distribution	x
BH03	**48819**	31.20	31.30	Moisture Content	x
BH03	**48822**	33.95	34.03	Moisture Content	x
BH03	**48824**	36.70	36.80	Particle Size Distribution	x
BH03	**48825**	38.60	38.70	Moisture Content	x
BH03	**48826**	38.95	39.05	Organic Matter Content	x
BH03	**48827**	39.25	39.30	Atterberg Limits	x
BH03	**48828**	39.45	39.55	Organic Matter Content	x
BH03	**48829**	39.80	39.83	Moisture Content	x
BH03	**48830**	40.65	40.77	Atterberg Limits	x
BH03	**48831**	41.20	41.25	pH	x
BH03	**48832**	41.30	41.50	Oedometer	x
BH03	**48833**	41.85	42.08	Triaxial - Unconsolidated / Undrained	x
BH03	**48834**	42.30	42.35	Moisture Content	x
BH03	**48835**	42.35	42.40	Organic Matter Content	x
BH03	**48836**	42.65	42.97	Triaxial - Unconsolidated / Undrained	x
BH03	**48837**	42.97	43.30	Oedometer	x
BH03	**48838**	44.05	44.20	Oedometer	x
BH03	**48839**	46.20	46.27	Organic Matter Content	x
BH03	**48840**	46.27	46.59	Triaxial - Unconsolidated / Undrained	x
BH03	**48841**	47.00	47.10	pH	x

BH03	**48842**	47.20	47.27	Moisture Content	x
BH03	**48843**	47.45	47.55	Organic Matter Content	x
BH03	**48844**	47.85	48.02	Oedometer	x
BH03	**48845**	48.20	48.30	Atterberg Limits	x
BH03	**48846**	48.45	48.70	Triaxial - Unconsolidated / Undrained	x
BH03	**48847**	49.00	49.10	Organic Matter Content	x
BH03	**48848**	49.30	49.40	Moisture Content	x
BH03	**48849**	63.15	63.22	Organic Matter Content	x
BH03	**48850**	63.38	63.43	pH	x
BH03	**48851**	63.50	63.55	Moisture Content	x
BH03	**48852**	63.90	63.95	Organic Matter Content	x
BH03	**48853**	64.30	64.35	Moisture Content	x
BH03	**48854**	64.90	64.95	Organic Matter Content	x
BH03	**48855**	65.50	65.60	Moisture Content	x
BH03	**48856**	66.95	67.05	Moisture Content	x
BH03	**48857**	68.40	68.45	Moisture Content	x
BH03	**48858**	70.40	70.50	Moisture Content	x
BH03	**48859**	70.75	70.85	Moisture Content	x
BH03	**48860**	71.60	71.70	Moisture Content	x
BH06	**50742**	5.25	5.50	Triaxial - Unconsolidated / Undrained	x
BH06	**50744**	16.20	16.50	Oedometer	x
BH06	**50745**	16.60	16.70	Moisture Content	x
BH06	**50746**	16.70	16.80	Atterberg Limits	x
BH06	**50747**	17.13	17.20	Organic Matter Content	x
BH06	**50748**	18.00	18.25	Triaxial - Unconsolidated / Undrained	x
BH06	**50749**	18.25	18.35	Moisture Content	x
BH06	**50750**	18.65	18.75	Atterberg Limits	x
BH06	**50851**	18.95	19.05	Organic Matter Content	x
BH06	**50852**	19.70	19.95	Oedometer	x
BH06	**50853**	20.00	20.25	Oedometer	x
BH06	**50854**	21.45	21.52	Moisture Content	x
BH06	**50855**	21.52	21.60	Atterberg Limits	x
BH06	**50856**	21.75	21.80	Organic Matter Content	x

Table 8: Summary of Soil Test Results in BH03 & BH06.

Location ID	Sample ID	Depth Top	Depth Base	Test	Result
BH04	**48901**	3.5	3.55	Moisture Content	**0.20%**
BH04	**48902**	5.4	5.48	Moisture Content	**0.60%**
BH04	**48903**	8.06	8.36	Deformability in Uniaxial Compression	**119.9MPa**
BH04	**48904**	9.3	9.36	Moisture Content	**0.30%**
BH04	**48905**	10.63	10.88	Deformability in Uniaxial Compression	**41.6MPa**
BH04	**48906**	11.77	11.83	Moisture Content	**0.20%**
BH04	**48907**	12.62	12.75	Point Load	**59.2MPa**
BH04	**48908**	12.85	13.1	Uniaxial Compressive Strength	**76MPa**
BH04	**48909**	13.1	13.25	Point Load	**52.7MPa**

BH04	**48910**	14.4	14.63	Deformability in Uniaxial Compression	**62.0MPa**
BH04	**48911**	14.63	14.74	Point Load	**49.2MPa**
BH04	**48912**	14.74	14.97	Uniaxial Compressive Strength	**86MPa**
BH04	**48913**	14.97	15.13	Point Load	**60.1MPa**
BH04	**48914**	11.77	11.83	Porosity / Density using Saturation and Calliper & Porosity / Density using Saturation and Buoyancy	**0.2/2.72**
BH04	**48915**	17.74	17.86	Point Load	**60.2MPa**
BH04	**48917**	18.12	18.2	Point Load	**56.5MPa**
BH04	**48918**	19.2	19.32	Point Load	**36.5MPa**
BH04	**48919**	20.05	20.12	Thin Section / Petrography	
BH04	**48920**	20.12	20.22	Point Load	**73.9MPa**
BH04	**48921**	20.22	20.5	Uniaxial Compressive Strength	**55MPa**
BH04	**48922**	20.8	20.85	Moisture Content	**0.40%**
BH04	**48923**	21.2	21.3	Point Load	**68.4MPa**
BH04	**48924**	21.8	21.9	Moisture Content	**1%**
BH04	**48925**	22.2	22.31	Point Load	**90.2MPa**
BH04	**48926**	22.6	22.78	Point Load	**60.1MPa**
BH04	**48927**	22.78	23.06	Uniaxial Compressive Strength	**53MPa**
BH04	**48928**	23.1	23.2	Point Load	**64.6MPa**
BH04	**48929**	21.8	21.9	Porosity / Density using Saturation and Calliper & Porosity / Density using Saturation and Buoyancy	**0.4/2.69**
BH04	**48930**	23.7	23.8	Point Load	**77.7MPa**
BH04	**48931**	23.8	24.1	Uniaxial Compressive Strength	**111MPa**
BH04	**48932**	24.17	24.28	Point Load	**74MPa**
BH04	**48933**	24.28	24.52	Uniaxial Compressive Strength	**91MPa**
BH04	**48934**	25.08	25.19	Point Load	**77.5MPa**
BH04	**48935**	25.19	25.41	Deformability in Uniaxial Compression	**64.1MPa**
BH04	**48936**	28.27	28.4	Porosity / Density using Saturation and Calliper	**0.5/2.65**
BH04	**48937**	27.91	28	Point Load	**89.4MPa**
BH04	**48938**	28.27	28.4	Moisture Content	**0.10%**
BH04	**48939**	28.4	28.44	Point Load	**68.3MPa**
BH04	**48941**	29.38	29.54	Indirect Tensile Strength by Brazilian Test	**5.97MPa**
BH04	**48943**	29.86	29.94	Point Load	**92MPa**
BH04	**48949**	30.93	30.03	Point Load	**76.6MPa**
BH04	**48950**	31.03	31.3	Uniaxial Compressive Strength	**76MPa**
BH04	**48951**	31.3	31.4	Point Load	**67.8MPa**
BH04	**48954**	31.66	31.7	Total Sulphur	**<0.1%**
BH04	**48955**	31.76	31.84	Point Load	**59.6MPa**
BH04	**48956**	31.84	31.93	Oxidisable Sulphur	**0.04**
BH04	**48957**	31.93	32.15	Uniaxial Compressive Strength	**78MPa**
BH04	**48958**	32.15	32.26	Point Load	**55.4MPa**
BH04	**48959**	32.26	32.35	pH	**9.3**
BH04	**48962**	32.5	32.57	Point Load	**78.8MPa**
BH04	**48963**	32.57	32.85	Uniaxial Compressive Strength	**92MPa**
BH04	**48964**	32.85	32.96	Point Load	**65.5MPa**

BH04	**48965**	33.12	33.16	Moisture Content	**0.10%**
BH04	**48966**	33.2	33.48	Deformability in Uniaxial Compression	**66.5MPa**
BH04	**48967**	33.48	33.6	Point Load	**49.9MPa**
BH04	**48968**	32.35	32.43	Porosity / Density using Saturation and Buoyancy	**0.4/2.69**
BH04	**48969**	34.56	34.59	Moisture Content	**0.30%**
BH04	**48970**	34.96	35	Moisture Content	**0.20%**
BH05	**48971**	0.65	0.73	Moisture Content	**0.30%**
BH05	**48972**	0.98	1.04	Moisture Content	**0.10%**
BH05	**48973**	1.41	1.5	Moisture Content	**0.10%**
BH05	**48974**	2.62	2.67	Porosity / Density using Saturation and Calliper	**0.4/2.68**
BH05	**48975**	2.8	2.96	Point Load	**27.8Mpa**
BH05	**48976**	1.41	1.5	Porosity / Density using Saturation and Buoyancy	**0.3/2.65**
BH05	**48977**	7.73	7.84	Point Load	**63MPa**
BH05	**48978**	8.1	8.25	Point Load	**43.8MPa**
BH05	**48979**	8.54	8.66	Point Load	**62MPa**
BH05	**48980**	8.9	8.96	Moisture Content	**0.10%**
BH05	**48981**	9.46	9.57	Point Load	**91.5MPa**
BH05	**48982**	9.57	9.77	Uniaxial Compressive Strength	**91MPa**
BH05	**48983**	9.77	9.92	Point Load	**55.4MPa**
BH05	**48984**	10.2	10.26	Point Load	**101.0MPa**
BH05	**48985**	11.3	11.45	Point Load	**43.1MPa**
BH05	**48986**	11.45	11.72	Uniaxial Compressive Strength	**86MPa**
BH05	**48987**	11.72	11.83	Point Load	**77.2MPa**
BH05	**48988**	12.92	13.07	Moisture Content	**0.30%**
BH05	**48989**	13.5	13.6	Point Load	**141.1MPa**
BH05	**48990**	13.7	13.81	Point Load	**67.3MPa**
BH05	**48991**	13.81	14.07	Uniaxial Compressive Strength	**94MPa**
BH05	**48992**	14.07	14.15	Point Load	**84.4MPa**
BH05	**48993**	14.27	14.4	Point Load	**74.0MPa**
BH05	**48994**	14.65	14.89	Uniaxial Compressive Strength	**72MPa**
BH05	**48995**	15.43	15.55	Point Load	**81.8MPa**
BH05	**48996**	15.95	16.22	Deformability in Uniaxial Compression	**57.0MPa**
BH05	**48997**	16.45	16.55	Point Load	**67.3MPa**
BH05	**48998**	16.87	17.19	Uniaxial Compressive Strength	**77MPa**
BH05	**48999**	17.97	18.06	Porosity / Density using Saturation and Buoyancy	**0.3/2.69**
BH05	**50701**	19.7	19.92	Indirect Tensile Strength by Brazilian Test	**3.39MPa**
BH05	**50702**	28.85	28.95	Porosity / Density using Saturation and Calliper	**0.4/2.69**
BH05	**50703**	22.07	22.21	Point Load	**54.3MPa**
BH05	**50704**	22.9	23	Point Load	**87.3MPa**
BH05	**50705**	23.94	24.05	Point Load	**67.2MPa**
BH05	**50706**	24.05	24.3	Deformability in Uniaxial Compression	**44.9MPa**
BH05	**50707**	24.73	24.85	Point Load	**66.4MPa**
BH05	**50708**	25.2	25.4	Deformability in Uniaxial Compression	**22.6MPa**

BH05	**50709**	26	26.12	Point Load	**76.4MPa**
BH05	**50710**	26.12	26.35	Deformability in Uniaxial Compression	**66.3MPa**
BH05	**50711**	27.68	27.88	Uniaxial Compressive Strength	**79MPa**
BH05	**50712**	28.75	28.85	Moisture Content	**0.10%**
BH05	**50715**	29.09	29.18	Total Sulphur	**<0.1**
BH05	**50716**	29.18	29.3	Oxidisable Sulphur	**<0.01**
BH05	**50717**	29.3	29.4	pH	**9.2**
BH05	**50718**	30.3	30.4	Moisture Content	**0.40%**
BH05	**50721**	30.88	30.92	Moisture Content	**0.30%**
BH05	**50725**	32.44	32.54	Point Load	**76.8MPa**
BH05	**50726**	32.54	32.6	Moisture Content	**0.20%**
BH05	**50727**	32.83	32.92	Point Load	**66.7MPa**
BH05	**50728**	32.92	33	Thin Section / Petrography	
BH05	**50729**	33	33.26	Uniaxial Compressive Strength	**116MPa**
BH05	**50730**	33.22	33.26	Porosity / Density using Saturation and Calliper	**0.6/2.69**
BH05	**50731**	33.5	33.7	Uniaxial Compressive Strength	**51MPa**
BH05	**50733**	33.92	33.16	Uniaxial Compressive Strength	**54MPa**
BH05	**50735**	34.5	34.7	Porosity / Density using Saturation and Buoyancy	**0.4/2.68**
BH05	**50736**	37.4	37.5	Point Load	**80.7MPa**
BH05	**50737**	37.5	37.82	Uniaxial Compressive Strength	**131MPa**
BH05	**50738**	37.82	37.92	Point Load	**77.2MPa**
BH05	**50740**	37.92	38.08	Point Load	**52.3MPa**

Table 9: Summary of Rock Test Results in BH04 & BH05

Sample	Test	Result
Bulk Sample	Aggregate Crushing Value	**23%**
Bulk Sample	Aggregate Impact Value	**17%**
Bulk Sample	Aggregate Abrasion Value	**12**
Bulk Sample	Polished Stone Value	**38**
Bulk Sample	Slake Durability	**99.40%**
Bulk Sample	Los Angeles Coefficient	**28**
Bulk Sample	Soundness by Magnesium Sulphate	**1**
Bulk Sample	10% Fines	**150kN**
Bulk Sample	Frost Heave	**3.3mm**

Table 10: Summary of Rock Test Results in Bulk Sample

3.8 In Situ Water Testing

Water samples were obtained from boreholes BH04, BH05 and BH06 and tested for pH, Temperature, Conductivity and Dissolved O_2. Three water samples were obtained and the pH, Temperature, Conductivity and dissolved O_2 data was acquired using a Watterra Pump with each borehole purged for at least 30 minutes. This work was carried out by Ronan Doyle of Ronan Doyle Monitoring Solutions, Ballinrobe County Mayo.

Borehole	pH	Temperature (^oC)	Conductivity (µS)	Dissolved O_2 (mg/l)
BH04	7.47	10.5	295	0.21
BH05	7.77	10.5	420	0.8
BH06	12.53	9.8	6187	0.8

Table 11: In Situ Water Testing Results

3.9 Permeability Testing

Falling Head and Packer Testing was carried out on boreholes BH04 and BH05. The ground conditions intersected in boreholes BH03 and BH06 was considered too unstable for permeability testing.

A falling head test was carried out in BH04 on the 5th of January 2016. The rods were removed from the hole and the water level in the borehole was recorded at 17.88m bgl before the test commenced. Initially a volume of 130 litres was pumped into the hole, upon cessation of pumping the water level recovered almost immediately (i.e. faster than the dip meter could be lowered into the hole). A second test was subsequently carried out and 500 litres were pumped into the hole and same rapid recovery to 17.88m bgl was observed.

Falling head tests were carried out in BH05 on the 7th of January 2016. The rods were removed from the hole and the water level in this borehole was recorded at 19.45m bgl before commencement of the test. Initially a volume of 215 litres was pumped into the hole and the hole recovered back to 19.42m bgl and had stabilised after 40 minutes. A second test using a greater volume of water was carried out and 1000 litres of water was pumped into the hole. This test had proceeded almost to conclusion when the water level rose slightly (c.1.0cm) and a obstruction could be felt in the hole. The driller ran the rods back into the hole to assist with the piezometer installation and found that there was clay in the hole from 19.3 to 20.8m. The Falling Head test data is presented in Appendix XI.

Packer testing was carried out in boreholes BH04 and BH05 on the 18th of December 2015 and the 6th of January 2016 respectively. Set up details are presented in Table 12 and the results in Appendix X.

Borehole	Top (m)	Bottom (m)	Midpoint (m)
BH04	18	20	19
BH04	21	23	22
BH04	24	26	25
BH04	28	30	29
BH05	36	38	37
BH05	30	32	31
BH05	24	27	25.5
BH05	20	23	21.5

Table 12: Packer Test Installation Details

The Packer Tests carried out at 28-30m and 21-23m in BH04 suffered from loss of water pressure due to cavities / fractures. For both of these tests only one stage could be measured. All of the scheduled packer tests were carried out in BH05.

It was noted that the water pressure recovery once pumping had ceased was instantaneous in all of the test intervals.

3.10 Water level Measurements

Throughout the ground investigation water level measurements were taken from all of the vertical drillholes, both during and after drilling. It should be noted that owing to ground instability and the need to keep holes open for the ground geophysical surveying, the bulk of the readings from boreholes BH03 and BH04 were taken when the holes were cased with PW steel casing, which extended from surface to the base of the hole.

APPENDIX I

Hole	East	North	Elevation
BH1	530370.592	728426.557	16.712
BH3	530023.824	728382.566	26.256
BH4	530150.783	728400.125	32.167
BH5	530186.649	728378.105	34.138
BH6	530125.143	728383.081	30.799

Survey name	Station	East	North	Elevation	Dip	Azimuth	Tool–	Gravity	Mag.Str.	Mag.Dip	Mag.X	Mag.Y	Mag.Z	Roll Angle	Mag.T/face	DLS
*	Metres	Metres	Metres	Metres	Degrees	Degrees	Centigrade	G	nT	Degrees	nT	nT	nT	Degrees	Degrees	deg./30m
BH-1	1	0	0	0	-11.5	268.3	11	1.000147	48955	67.9	18396	0	45367	90	292.4	0
BH-1	4	-2.94	-0.09	-0.6	-11.5	268.1	11	1.00047	48954	67.9	18424	0	45355	90	292.4	1.9
BH-1	7	-5.88	-0.18	-1.2	-11.5	268.4	11	1.000677	48946	67.9	18415	0	45350	89.7	292.1	2.3
BH-1	10	-8.81	-0.28	-1.8	-11.7	267.9	11	1.00063	49023	67.9	18436	0	45424	89	291.5	5.4
BH-1	13	-11.75	-0.39	-2.41	-11.7	267.9	11	1.001172	49022	67.9	18468	0	45410	88.4	290.9	0.4
BH-1	16	-14.68	-0.5	-3.02	-11.8	267.6	11	1.000628	49027	67.9	18422	0	45434	88.4	290.8	3
BH-1	19	-17.62	-0.62	-3.63	-11.9	267.5	11	1.00041	49014	67.9	18451	0	45408	88.2	290.7	0.9
BH-1	22	-20.54	-0.81	-4.27	-12.6	265.4	11	1.002129	49028	68.5	17966	0	45618	89.2	291	22.5
BH-1	25	-23.47	-0.99	-4.91	-12.1	267.2	11	1.000351	49037	67.9	18457	0	45431	88.7	291.1	19
BH-1	28	-26.4	-1.13	-5.54	-12.2	267.3	11	1.000495	49044	67.9	18458	0	45438	88.4	290.8	1.2
BH-1	31	-29.33	-1.28	-6.18	-12.4	267.1	11	1.000687	49069	67.9	18452	0	45467	88.5	290.9	3.2
BH-1	34	-32.25	-1.43	-6.83	-12.6	266.9	11	1.000132	49044	67.9	18419	0	45454	88.4	290.8	2.8
BH-1	37	-35.18	-1.58	-7.48	-12.6	267.1	11	1.000742	49065	67.9	18458	0	45460	88.3	290.7	2.2
BH-1	40	-38.1	-1.73	-8.13	-12.6	267.1	11	1.000358	49075	67.9	18479	0	45463	88.3	290.8	0.4
BH-1	43	-41.02	-1.88	-8.79	-12.6	267.1	11	1.000171	49057	67.9	18429	0	45464	88.5	290.9	0.6
BH-1	46	-43.95	-2.02	-9.44	-12.5	267.3	11	1.000035	49054	67.9	18466	0	45446	88.8	291.3	2
BH-1	49	-46.87	-2.17	-10.09	-12.7	267	11	1.000317	49034	67.9	18438	0	45435	89.4	291.8	2.7
BH-1	52	-49.8	-2.32	-10.75	-12.7	267.1	11	1.000291	49062	68	18415	0	45475	89.7	292.1	0.4
BH-1	55	-52.72	-2.47	-11.41	-12.7	266.9	11	1.000127	49043	67.9	18450	0	45440	90.4	292.9	2
BH-1	58	-55.64	-2.61	-12.06	-12.5	267.8	11	0.99969	49044	67.6	18658	0	45356	90.8	293.6	9.5
BH-1	61	-58.57	-2.74	-12.72	-12.8	267.1	11	1.000477	49098	67.9	18474	0	45490	92.3	294.8	8
BH-1	64	-61.49	-2.89	-13.38	-12.8	267	11	1.00001	49037	67.9	18460	0	45430	93.1	295.6	0.4
BH-1	67	-64.41	-3.04	-14.05	-12.9	266.9	11	1.000212	49044	67.9	18458	0	45438	93.5	296	1.5
BH-1	70	-67.33	-3.2	-14.72	-12.9	267	11	1.0002	49029	67.9	18458	0	45422	94.5	297	1.4
BH-1	73	-70.25	-3.35	-15.39	-12.9	266.9	11	1.000355	49071	67.9	18437	0	45476	94.9	297.4	1.7
BH-1	76	-73.17	-3.51	-16.06	-12.9	267	11	1.000287	49068	67.8	18512	0	45442	95.4	297.9	1.8
BH-1	79	-76.11	-3.53	-16.68	-10.9	272	11	0.992033	49037	67.9	18432	0	45441	95.8	298.3	52.4

Survey name	Station	East	North	Elevation	Dip	Azimuth	Tool–	Gravity	Mag.Str.	Mag.Dip	Mag.X	Mag.Y	Mag.Z	Roll Angle	Mag.T/face	DLS
*	Metres	Metres	Metres	Metres	Degrees	Degrees	Centigrade	G	nT	Degrees	nT	nT	nT	Degrees	Degrees	deg./30m
BH-1	82	-79.04	-3.56	-17.3	-13	266.9	11	1.000459	49018	67.9	18469	0	45406	96.3	298.8	53.7
BH-1	85	-81.96	-3.72	-17.98	-13.2	266.6	11	1.000487	49052	67.9	18490	0	45434	96.5	299.1	3.2
BH-1	88	-84.87	-3.89	-18.66	-13.1	266.8	11	1.000296	49038	67.9	18437	0	45440	96.8	299.2	1.2
BH-1	91	-87.79	-4.06	-19.34	-13.1	266.8	11	1.000282	49031	67.9	18455	0	45426	96.8	299.3	0.7
BH-1	94	-90.71	-4.22	-20.03	-13.1	266.7	11	1.000122	49080	67.9	18447	0	45482	97.2	299.7	1
BH-1	97	-93.62	-4.39	-20.71	-13.2	266.7	11	1.000303	49066	67.9	18470	0	45457	97.6	300.1	0.6
BH-1	100	-96.54	-4.55	-21.4	-13.2	266.7	11	1.000268	49068	67.8	18503	0	45445	97.5	300.1	0.5
BH-1	103	-99.47	-4.63	-22.05	-11.8	270.2	11	0.995246	49056	68.6	17887	0	45678	98.2	300	37
BH-1	106	-102.39	-4.71	-22.7	-13.3	266.7	11	1.00031	49060	67.9	18480	0	45446	97.7	300.2	37.4
BH-1	109	-105.31	-4.88	-23.39	-13.3	266.6	11	1.000017	49021	67.9	18429	0	45425	97.8	300.3	0.7
BH-1	112	-108.22	-5.05	-24.08	-13.4	266.5	11	1.000223	49056	67.9	18482	0	45442	98	300.5	1.5
BH-1	115	-111.13	-5.22	-24.78	-13.4	266.7	11	1.000889	49063	67.9	18460	0	45457	98	300.5	1.4
BH-1	118	-114.05	-5.4	-25.48	-13.5	266.5	11	1.000317	49027	67.9	18468	0	45416	98.3	300.8	2.1
BH-1	121	-116.96	-5.58	-26.18	-13.4	266.6	11	1.000141	49042	67.9	18448	0	45440	98.3	300.8	1.2
BH-1	124	-119.87	-5.75	-26.88	-13.5	266.5	11	1.000272	49046	67.9	18477	0	45433	98.3	300.9	0.9
BH-1	127	-122.78	-5.93	-27.58	-13.5	266.5	11	0.99995	49034	67.9	18473	0	45422	98.3	300.8	0.6
BH-1	130	-125.69	-6.11	-28.28	-13.6	266.4	11	1.000699	49079	67.9	18430	0	45487	98.2	300.7	0.8
BH-1	133	-128.6	-6.29	-28.99	-13.6	266.6	11	1.00039	49055	67.9	18443	0	45456	98.2	300.8	1.6
BH-1	136	-131.51	-6.47	-29.7	-13.7	266.3	11	0.999701	49064	67.9	18444	0	45466	98	300.5	2.8
BH-1	139	-134.42	-6.65	-30.41	-13.7	266.4	11	1.000129	49052	67.9	18462	0	45445	98.2	300.7	0.9
BH-1	142	-137.33	-6.83	-31.12	-13.8	266.4	11	1.000614	49054	67.9	18477	0	45441	98.7	301.3	0.9
BH-1	145	-140.24	-7.02	-31.83	-13.8	266.3	11	1.000523	49075	67.9	18474	0	45465	98.7	301.2	0.7
BH-1	148	-143.14	-7.21	-32.55	-13.8	266.3	11	1.000394	49034	67.9	18471	0	45422	98.9	301.5	0.6

Survey name	Station	East	North	Elevation	Dip	Azimuth	Tool–	Gravity	Mag.Str.	Mag.Dip	Mag.X	Mag.Y	Mag.Z	Roll Angle	Mag.T/face	DLS
*	Metres	Metres	Metres	Metres	Degrees	Degrees	Centigrade	G	nT	Degrees	nT	nT	nT	Degrees	Degrees	deg./30m
BH-1	151	-146.05	-7.39	-33.26	-13.8	266.4	11	1.000164	49043	67.9	18474	0	45430	98.9	301.5	1.5
BH-1	154	-148.96	-7.57	-33.98	-13.9	266.4	11	1.000365	49066	67.9	18451	0	45464	99.1	301.6	1
BH-1	157	-151.87	-7.76	-34.7	-13.9	266.3	11	1.000252	49055	67.8	18506	0	45430	99.2	301.8	1
BH-1	160	-154.77	-7.95	-35.43	-14	266.2	11	0.999691	49068	67.9	18477	0	45456	99.2	301.7	0.6
BH-1	163	-157.68	-8.14	-36.15	-14	266.3	11	1.001008	49040	67.9	18411	0	45453	99.3	301.8	0.5
BH-1	166	-160.58	-8.33	-36.88	-14	266.2	11	0.999912	49061	67.9	18462	0	45455	100.3	302.8	0.6
BH-1	169	-163.48	-8.52	-37.6	-14	266.3	11	1.00026	49044	67.9	18480	0	45430	100.3	302.9	1.2
BH-1	172	-166.39	-8.71	-38.33	-14.1	266.4	11	1.000443	49080	67.9	18462	0	45476	100.3	302.8	0.4
BH-1	175	-169.29	-8.89	-39.06	-14.1	266.2	11	0.999983	49089	67.9	18458	0	45487	100.3	302.8	1.5

APPENDIX II

Rotary Core Log

Borehole No.
BH01
Sheet 1 of 28

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56	Hole Type RC
Location:	Galway		Level: 16.71	Scale 1:50
Client:	Galway County Council		Dates: 13/11/2015 - 21/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description
				TCR	SCR	RQD				
		0.00 - 5.60								Concrete Plinth
		5.60 - 6.30	14	100	60	41	5.60	11.11		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. (Core invert not marked)
		6.30 - 7.52	3	100	100	100	6.30	10.41		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Sub-vertical stylolites, occasional coarse shelled bioclast (Brachiopod)
		7.52 - 10.15	6	100	89	81	7.52	9.19		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Occasional fine grained scattered bioclasts, minor stylolites

Continued on next sheet

Remarks

Rotary Core Log

Borehole No.
BH01
Sheet 2 of 28

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords:	530370.59 - 728426.56	Hole Type RC
Location:	Galway		Level:	16.71	Scale 1:50
Client:	Galway County Council		Dates:	13/11/2015 - 21/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description
				TCR	SCR	RQD				
		10.15 - 11.10	2	88	88	88	10.15	6.56		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Very occasional fine grained bioclast
		11.10 - 12.66	5	100	44	38	11.10	5.61		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. pellety / slightly oolitic texture
		12.66 - 14.20	2	100	100	96	12.66	4.05		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. pellety / slightly oolitic intervals with small rounded bioclasts
		14.20 - 14.58	18	100	29	29	14.20	2.51		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Intersecting conjugate joints
		14.58 - 15.46	2	100	100	100	14.58	2.13		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Minor white calcite fill along joint
		15.46 - 15.86	15	100	25	0	15.46	1.25		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. White calcite fill and weak oxidation along steeply dipping joint surface
		15.86 - 17.04	2	100	100	100	15.86	0.85		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. pellety / slightly oolitic texture, minor thick shelled brachiopods
		17.04 - 21.07	3	97	87	86	17.04	-0.33		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Slightly pellety scattered fine bioclastic debris with occasional coarse shelled brachiopod fragment

Continued on next sheet

Remarks

Rotary Core Log

Borehole No.
BH01
Sheet 3 of 28

Project Name: Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56	Hole Type RC
Location: Galway		Level: 16.71	Scale 1:50
Client: Galway County Council		Dates: 13/11/2015 - 21/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
		21.07 - 21.60	23	100	53	40	21.07	-4.36		Strong. fresh, grey / pale grey, fine to medium grained, massive LIMESTONE. minor bioclastic debris and white calcite veinlets, basal 10cm is rubble
		21.60 - 22.75	3	100	100	100	21.60	-4.89		Strong. fresh, grey / pale grey, fine to medium grained, massive LIMESTONE. Occasional coarse shelled brachiopod fragments
		22.75 - 24.34	4	100	78	65	22.75	-6.04		Strong. fresh, grey / pale grey, fine to medium grained, massive LIMESTONE. Thin, discontinuous white/pink dolomite veinlets dipping at 45'. Minor scattered fine grained bioclasts and very fine stylolites
		24.34 - 24.73	15	92	0	0	24.34	-7.63		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Cavity developed with weak oxidation and pitting / dissolution on contacts
		24.73 - 31.68	2	100	100	100	24.73	-8.02		Strong. fresh, grey, fine to medium grained, massive LIMESTONE. with hairline white calcite veinlets dipping at 50 - 70'. Minor scattered poorly sorted bioclastic debris. Fine sub-vertical stylolites

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Continued on next sheet

Remarks

Rotary Core Log

Borehole No.
BH01
Sheet 4 of 28

Project Name: Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56	Hole Type RC
Location: Galway		Level: 16.71	Scale 1:50
Client: Galway County Council		Dates: 13/11/2015 - 21/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description
				TCR	SCR	RQD				
									▦	
		31.68 - 33.22	7	100	77	55	31.68	-14.97	▦	Strong. fresh, grey, fine to medium grained, massive LIMESTONE. fine sub-vertical stylolites. 31.78m calcite filled vugs locally developed
		33.22 - 37.10	2	100	97	95	33.22	-16.51	▦	Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Small scattered bioclasts, very rare coarse shell and coral fragment. Minor fine stylolites
		37.10 - 38.70	6	100	59	51	37.10	-20.39	▦	Strong. fresh, brownish pale grey, fine to medium grained, massive LIMESTONE. Fine grained scattered bioclastic debris, minor very fine stylolites
		38.70 - 40.45	2	100	100	100	38.70	-21.99	▦	Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Very minor scattered bioclastic debris, minor orange limonitic staining along a joint surface at 39.35m

Continued on next sheet

Remarks

Rotary Core Log

Borehole No.
BH01
Sheet 5 of 28

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56
Hole Type	RC		
Location:	Galway	Level:	16.71
Scale	1:50		
Client:	Galway County Council	Dates:	13/11/2015 - 21/12/2015
Logged By	Dave Blaney		

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
		40.45 - 43.30	3	100	90	88	40.45	-23.74		Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Minor bioclastic debris, and fine stylolites
		43.30 - 44.30	6	90	9	0	43.30	-26.59		Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Fine vuggy texture and faint stylolites
		44.30 - 52.98	6	100	96	91	44.30	-27.59		Strong. fresh, light grey, fine to medium grained, massive LIMESTONE. Scattered bioclastic debris, fragments of coarse shelled brachiopods or solitary corals. locally developed fine vuggy texture (49.1 - 49.55m). White calcite veinlets dip 90', azimuth 020' to core invert

Continued on next sheet

Remarks

Rotary Core Log

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56
Location:	Galway		Level: 16.71
Client:	Galway County Council		Dates: 13/11/2015 - 21/12/2015

Borehole No.
BH01
Sheet 6 of 28

Hole Type
RC

Scale
1:50

Logged By
Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
		52.98 - 53.74	9	97	37	13	52.98	-36.27		Strong. fresh, light grey, fine to medium grained, massive LIMESTONE. Minor fine stylolites
		53.74 - 56.10	3	94	94	90	53.74	-37.03		Strong. fresh, light grey, fine to medium grained, massive LIMESTONE. Very rare small bioclastic fragments, fine stylolites
		56.10 - 58.60	3	100	96	92	56.10	-39.39		Strong. fresh, grey, medium grained, massive LIMESTONE. Pellety texture with scattered small bioclastic fragments and faint stylolites.
							58.60	-41.89		Strong. fresh, light grey, fine to medium grained, massive LIMESTONE. Minor bioclastic debris, and fine stylolites

Depth scale: 51, 52, 53, 54, 55, 56, 57, 58, 59, 60

Continued on next sheet

Remarks

Rotary Core Log

Borehole No.
BH01
Sheet 7 of 28

Project Name: Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56	Hole Type RC
Location: Galway		Level: 16.71	Scale 1:50
Client: Galway County Council		Dates: 13/11/2015 - 21/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
		58.60 - 61.47	3	100	99	99				
		61.47 - 62.25	10	100	55	47	61.47	-44.76		Strong. fresh, light grey, fine to medium grained, massive LIMESTONE. Fine vuggy texture, 61.94m a 1cm thick white calcite vein dipping at 80' azimuth 185' to core invert
		62.25 - 63.73	1	100	100	100	62.25	-45.54		Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Occasional fine stylolite
		63.73 - 64.22	10	94	69	61	63.73	-47.02		Strong. fresh, grey/light grey, fine to medium grained, massive LIMESTONE. Minor bioclastic debris, and fine stylolites. Some coarse vugs (6mm wide) irregular shaped with orange/brown limonitic infill
		64.22 - 67.85	3	100	100	100	64.22	-47.51		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Incipient pellety texture , scattered bioclastic debris, and faint stylolites
		67.85 - 68.78	9	92	77	60	67.88	-51.17		Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Minor bioclastic debris, and fine stylolites

Continued on next sheet

Remarks

Rotary Core Log

Borehole No.
BH01
Sheet 8 of 28

Project Name: Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56	Hole Type RC
Location: Galway		Level: 16.71	Scale 1:50
Client: Galway County Council		Dates: 13/11/2015 - 21/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
		68.78 - 72.31	3	98	96	96				
		72.31 - 73.39	6	100	30	19	72.31	-55.60		Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Minor bioclastic debris, and fine stylolites. Axial parallel jointing
		73.39 - 75.70	3	100	94	94	73.39	-56.68		Strong. fresh, pale grey, fine grained, massive LIMESTONE. Minor fine stylolites
		75.70 - 76.37	12	96	67	16	75.70	-58.99		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE.
		76.37 - 77.60	2	100	100	95	76.37	-59.66		Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Fine stylolites
		77.60 - 78.20	20	100	12	0	77.60	-60.89		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. 77.85m 1cm thick white calcite vein, 78.16m 1cm thick white orange calcite vein (Fe stains)
							78.20	-61.49		Strong. fresh, pale grey, fine grained, massive LIMESTONE. Numerous stylolites

Continued on next sheet

Remarks

Rotary Core Log

Borehole No.	**BH01**	Sheet 9 of 28	
Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	
Co-ords:	530370.59 - 728426.56	Hole Type	RC
Location:	Galway		
Level:	16.71	Scale	1:50
Client:	Galway County Council		
Dates:	13/11/2015 - 21/12/2015	Logged By	Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description
				TCR	SCR	RQD				
		78.20 - 86.15	3	99	99	98				
		86.15 - 88.77	2	100	96	96	86.15	-69.44		Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Occasional stylolites and fine grained bioclastic debris. 87.06m - 1cm thick white calcite vein
		88.77 - 90.30	7	100	49	23	88.77	-72.06		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. 90.09m - 2cm thick white calcite vein. Locally developed fine vuggy texture

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Remarks

Rotary Core Log

Borehole No.
BH01
Sheet 10 of 28

Project Name: Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56	Hole Type RC
Location: Galway		Level: 16.71	Scale 1:50
Client: Galway County Council		Dates: 13/11/2015 - 21/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description	
		90.30 - 95.95	2	100	99	98	90.30	-73.59		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Minor faint stylolites	91 92 93 94 95
		95.95 - 100.33	3	99	94	89	95.95	-79.24		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. small scattered bioclasts with some large (7cm dia.) coarse shelled brachiopods	96 97 98 99 100

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Remarks

Rotary Core Log

Borehole No.
BH01
Sheet 11 of 28

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords:	530370.59 - 728426.56	Hole Type RC
Location:	Galway		Level:	16.71	Scale 1:50
Client:	Galway County Council		Dates:	13/11/2015 - 21/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
									▦	
		100.33 - 102.74	6	97	85	71	100.33	-83.62	▦	Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Scattered small partially oxidised vugs. 101.4 & 101.43m 1cm thick white calcite veins dip 90' Azimuth 360'
		102.74 - 105.90	3	100	99	99	102.74	-86.03	▦	Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Fine bioclastic debris scattered throughout
		105.90 - 108.60	2	100	100	99	105.90	-89.19	▦	Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Thin (c.1mm), randomly orientated white / brown calcite veinlets over top 40cm. scattered fine bioclastic debris and fine stylolites
							108.60	-91.89	▦	Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Occasional scattered fine bioclastic debris and fine stylolites . Minor white calcite veining dipping at 85' to 180'

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Remarks

Rotary Core Log

Borehole No.	**BH01**
Sheet 12 of 28	
Project Name:	Lackagh Quarry Preliminary Ground Investigation
Project No.	Lackagh Quarry
Co-ords:	530370.59 - 728426.56
Hole Type	RC
Location:	Galway
Level:	16.71
Scale	1:50
Client:	Galway County Council
Dates:	13/11/2015 - 21/12/2015
Logged By	Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description
				TCR	SCR	RQD				
		108.60 - 111.55	5	100	98	86				
		111.55 - 113.73	1	100	100	100	111.55	-94.84		Strong. fresh, grey, fine grained, massive LIMESTONE. Fine black stylolites
		113.73 - 114.33	3	100	0	0	113.73	-97.02		Strong. fresh, grey, fine grained, massive LIMESTONE. Fine grained bioclastic debris. Axial parallel jointing
		114.33 - 119.52	1	100	100	98	114.33	-97.62		Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Disseminated very fine grained bioclastic debris
							119.52	-102.81		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Faint pellety texture, etched stylolites and scattered small vugs, often

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Remarks

Rotary Core Log

Borehole No.	**BH01**	Sheet 13 of 28	
Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No.	Lackagh Quarry
Co-ords:	530370.59 - 728426.56	Hole Type	RC
Location:	Galway	Level:	16.71
Scale	1:50		
Client:	Galway County Council	Dates:	13/11/2015 - 21/12/2015
Logged By	Dave Blaney		

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
		119.52 - 127.29	4	100	95	87				weakly oxidised. Disseminated fine grained bioclastic debris
		127.29 - 128.75	6	99	97	82	127.29	-110.58		Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Incipient mottled texture and scattered fine bioclastic debris.
							128.75	-112.04		Strong. fresh, dark grey, fine to medium grained, massive LIMESTONE. Wispy black argillaceous partings. Scattered fine bioclastic debris with some coarse shelled brachiopods / gastropods. thick black stylolites with argillic infill. Occasional white calcite veinlet

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Remarks

Rotary Core Log

Project Name: Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56	Borehole No. **BH01** Sheet 14 of 28
Location: Galway		Level: 16.71	Hole Type RC
			Scale 1:50
Client: Galway County Council		Dates: 13/11/2015 - 21/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description	
				TCR	SCR	RQD					
		128.75 - 134.90	1	100	97	97					131 132 133 134
		134.90 - 136.05	4	84	84	84	134.90	-118.19		Strong. fresh, dark grey, fine to medium grained, massive LIMESTONE. Wispy black argillaceous partings. Scattered fine bioclastic debris with some coarse shelled brachiopods.	135
		136.05 - 137.52	3	100	100	95	136.05	-119.34		Strong. fresh, dark grey, fine to medium grained, massive LIMESTONE. Weak intraclastic breccia texture minor stylolites and black argillic partings	136 137
		137.52 - 141.84	2	100	100	100	137.52	-120.81		Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Small scattered bioclasts, incipient intraclastic breccia texture locally developed minor discontinuous white calcite veinlets	138 139 140

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Remarks

Rotary Core Log

				Borehole No.	**BH01** Sheet 15 of 28
Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56	Hole Type	RC
Location:	Galway		Level: 16.71	Scale	1:50
Client:	Galway County Council		Dates: 13/11/2015 - 21/12/2015	Logged By	Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
		141.84 - 142.93	3	100	100	100	141.84	-125.13		Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Small scattered bioclasts, incipient bioturbated / burrowed texture
		142.93 - 143.70	0	100	100	100	142.93	-126.22		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE.. Pellety / almost oolitic texture
		143.70 - 148.30	1	100	100	100	143.70	-126.99		Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Intraclastic breccia texture sub-rounded clasts 0.5 - 2.0cm dia. possibly related to bioturbation / burrowing. Minor stylolites and a very rare bioclast
		148.30 - 148.90	10	100	0	0	148.30	-131.59		Core is crosscut by a 2cm thick band of weak / very weak, fresh, fine grained Black MUDSTONE. Soft / Friable texture, locally altered to clay dip 32' to 060'
							148.90	-132.19		Strong. fresh, dark grey / black, fine to medium grained, massive LIMESTONE. Intraclastic breccia texture poorly sorted, very irregular / angular clasts of fine grained limestone (micrite) in a black / dark grey locally argillaceous matrix. Intensity of brecciation decreasing with depth

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Remarks

Rotary Core Log

Project Name: Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56	Borehole No. **BH01** Sheet 16 of 28
Location: Galway		Level: 16.71	Hole Type RC
Client: Galway County Council		Dates: 13/11/2015 - 21/12/2015	Scale 1:50
			Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description	
		148.90 - 154.60	2	100	99	97					151 152 153 154
		154.60 - 161.75	1	100	100	71	154.60	-137.89		Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Stylolites locally up to 3mm thick. Minor bioclastic debris. Locally developed incipient intraclastic breccia / bioturbation textures	155 156 157 158 159 160

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Remarks

Rotary Core Log

Project Name: Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords:	530370.59 - 728426.56	Borehole No. **BH01** Sheet 17 of 28
Location: Galway		Level:	16.71	Hole Type RC
Client: Galway County Council		Dates:	13/11/2015 - 21/12/2015	Scale 1:50
				Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	SCR	RQD	Depth (m)	Level (m)	Legend	Stratum Description	
									▨		161
		161.75 - 166.30	1	100	100	98	161.75	-145.04	▨	Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Locally developed pellety / oolitic texture. Scattered bioclastic debris	162 163 164 165 166
		166.30 - 168.90	1	100	100	99	166.30	-149.59	▨	Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Numerous coarse bioclasts and white calcite infilling small voids	167 168
							168.90	-152.19	▨	Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Slight pellety texture. Scattered fine to medium grained bioclasts	169 170

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Remarks

Rotary Core Log

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56	Borehole No. **BH01** Sheet 18 of 28
				Hole Type RC
Location:	Galway		Level: 16.71	Scale 1:50
Client:	Galway County Council		Dates: 13/11/2015 - 21/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description	
		168.90 - 172.00	1	100	100	100			▦		171
							172.00	-155.29	▦	Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE.	172
key key incorrect incorrect key key incorrect incorrect key key		172.00 - 175.65	2	100	100	99			▦		173 174 175
							175.65	-158.94	▦	Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Scattered coarse shelled brachiopods	176
		175.65 - 177.00	1	100	100	100			▦		
							177.00	-160.29	▦	Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Minor stylolites, some up to 2mm thick. Scattered fine bioclastic debris	177
		177.00 - 182.50	1	100	100	100			▦		178 179 180

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Remarks

Rotary Core Log

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56	Borehole No. **BH01** Sheet 19 of 28
Location:	Galway		Level: 16.71	Hole Type RC
Client:	Galway County Council		Dates: 13/11/2015 - 21/12/2015	Scale 1:50
				Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description	
									▦		181 182
		182.50 - 186.80	1	100	100	99	182.50	-165.79	▦	Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Locally developed incipient intraclastic breccia texture. Fine stylolites and minor bioclasts	183 184 185 186
		186.80 - 189.00	0	0	0	0	186.80	-170.09		Cavity - No recovery. Pitting / dissolution textures and slight brown oxidation on contacts	187 188
		189.00 - 190.30		100	0	0	189.00	-172.29	▤	Soft to firm, light brown, fine grained sandy CLAY. Some tabular / angular clasts of light brown oxidised mudstone within the clay	189 190

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Remarks

Rotary Core Log

Borehole No.	BH01	Sheet 20 of 28	
Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	
Co-ords:	530370.59 - 728426.56	Hole Type	RC
Location:	Galway		
Level:	16.71	Scale	1:50
Client:	Galway County Council		
Dates:	13/11/2015 - 21/12/2015	Logged By	Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
			0							
		190.30 - 191.20	0	100	100	100	190.30	-173.59		Strong. fresh, grey, fine to medium grained, massive LIMESTONE.
		191.20 - 192.85	8	100	64	41	191.20	-174.49		Strong. fresh, grey / dark grey, fine to medium grained, massive LIMESTONE.
		192.85 - 195.70	1	100	100	100	192.85	-176.14		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Light brown sandy clay coating joint surfaces
		195.70 - 198.70	1	100	100	100	195.70	-178.99		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Scattered coarse shelled brachiopods
							198.70	-181.99		Strong. fresh, light grey / grey, fine to medium grained, massive LIMESTONE. Occasional coarse shelled brachiopod, locally developed incipient intraclastic breccia texture

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Rotary Core Log

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords:	530370.59 - 728426.56	Borehole No. **BH01** Sheet 21 of 28
Location:	Galway		Level:	16.71	Hole Type RC
Client:	Galway County Council		Dates:	13/11/2015 - 21/12/2015	Scale 1:50
					Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
		198.70 - 203.00	2	91	91	91				
		203.00 - 203.90	9	94	94	56	203.00	-186.29		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Minor coarse shelled brachiopods. Joints coated with light brown fine sandy clay
		203.90 - 207.50	1	100	98	98	203.90	-187.19		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Scattered coarse shelled brachiopods
							207.50	-190.79		Strong. fresh, grey, fine to medium grained, massive LIMESTONE.

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Remarks

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Rotary Core Log

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Borehole No. **BH01** Sheet 22 of 28
Co-ords:	530370.59 - 728426.56		Hole Type RC
Location:	Galway	Level: 16.71	Scale 1:50
Client:	Galway County Council	Dates: 13/11/2015 - 21/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
		207.50 - 214.50	1	100	100	99				
		214.50 - 216.90	2	100	90	90	214.50	-197.79		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. disseminated bioclastic debris
		216.90 - 217.60	3	100	100	100	216.90	-200.19		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Slightly vuggy with minor oxidation focused upon vugs
		217.60 - 221.55	4	97	87	78	217.60	-200.89		Strong. fresh, light grey / grey, fine to medium grained, massive LIMESTONE.

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Remarks

Rotary Core Log

Borehole No.
BH01
Sheet 23 of 28

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56	Hole Type RC
Location:	Galway		Level: 16.71	Scale 1:50
Client:	Galway County Council		Dates: 13/11/2015 - 21/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
		221.55 - 223.55	5	100	98	96	221.55	-204.84		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Minor oxidation and light brown clay localised along joints and along some stylolites
		223.55 - 226.55	3	97	84	81	223.55	-206.84		Strong. fresh, pale grey/ grey, medium grained, massive LIMESTONE. Distinct pellety texture, fine grained bioclastic debris. 226.4 - 226.5 evidence of oxidation, dissolution (pitting) along a shallowly dipping joint plane
		226.55 - 229.10	3	100	97	95	226.55	-209.84		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. slight dissolution and oxidation focused on some joint surfaces
		229.10 - 229.20	0	0	0	0	229.10	-212.39		Cavity infilled with light brown soft / firm sticky clay
							229.20	-212.49		Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Slight discolouration and oxidation along some joint surfaces

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Remarks

Rotary Core Log

			Borehole No. **BH01** Sheet 24 of 28
Project Name: Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56	Hole Type RC
Location: Galway		Level: 16.71	Scale 1:50
Client: Galway County Council		Dates: 13/11/2015 - 21/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description	
				TCR	SCR	RQD					
		229.20 - 231.10	4	95	91	86			▦		231
		231.10 - 233.20	1	100	98	95	231.10	-214.39	▦	Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE.	232 233
		233.20 - 234.15	11	91	79	45	233.20	-216.49	▦	Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Joints and fractures infilled with light brown fine / medium grained sand. 232.78 2cm white calcite vein	234
		234.15 - 237.55	6	99	80	70	234.15	-217.44	▦	Strong. fresh, grey, fine to medium grained, massive LIMESTONE. Locally developed fine vuggy texture. 236.6m joint with intense bright orange Fe Staining.	235 236 237
		237.55 - 239.20	0	0	0	0	237.55	-220.84		CAVITY - coarse grained yellow sand and angular gravel with some light brown silt. Recover 30 - 35%	238 239
							239.20	-222.49	▦	Strong. fresh, light grey / grey, fine to medium grained, massive LIMESTONE. Locally developed coarse vuggy texture - vugs up to 5mm dia.	240

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Remarks

Rotary Core Log

Borehole No.
BH01
Sheet 25 of 28

Project Name: Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords:	530370.59 - 728426.56	Hole Type RC
Location: Galway		Level:	16.71	Scale 1:50
Client: Galway County Council		Dates:	13/11/2015 - 21/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
		239.20 - 241.40	6	50	19	13			▦	
		241.40 - 243.90	4	100	97	95	241.40	-224.69	▦	Strong. fresh, pale grey, fine to medium grained, massive LIMESTONE. Scattered poorly sorted bioclastic debris. Fine grained orange brown sand coating joint surfaces
		243.90 - 245.58	7	85	36	29	243.90	-227.19	▦	Strong. slightly weathered, pale grey, fine to medium grained, massive LIMESTONE. 243.9-244.35m axial parallel discontinuity with black argillaceous lamina. Orange brown clayey sand coating joint surfaces
		245.58 - 247.25	0	0	0	0	245.58	-228.87		CAVITY - 5% recovery of yellow brown fine to medium grained sand
		247.25 - 248.37	4	100	61	38	247.25	-230.54	▦	Strong. fresh, pale grey / grey, mottled, fine to medium grained, massive LIMESTONE. Fine vuggy texture with minor oxidation / Fe staining localised within the vugs. Some axial parallel jointing
		248.37 - 250.20	3	100	97	93	248.37	-231.66	▦	Strong. fresh, dark grey, medium grained, massive LIMESTONE. Poorly sorted bioclastic debris

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Rotary Core Log

Borehole No.
BH01
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Project Name: Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56	Hole Type RC
Location: Galway		Level: 16.71	Scale 1:50
Client: Galway County Council		Dates: 13/11/2015 - 21/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description
				TCR	SCR	RQD				
		250.20 - 253.00	2	100	98	98	250.20	-233.49		Strong. fresh, dark grey, medium grained, massive LIMESTONE. Poorly sorted bioclastic debris. Discontinuous randomly orientated white calcite veinlets
		253.00 - 255.50	2	100	92	92	253.00	-236.29		Strong. fresh, grey, medium grained, massive LIMESTONE. Scattered poorly sorted bioclastic debris. Incipient intraclastic breccia texture
		255.50 - 255.90	7	100	0	0	255.50	-238.79		Strong. grey LIMESTONE cross cut by cavity / dissolution zone bright orange staining and dissolution textures on cavity contact
		255.90 - 256.90	4	100	60	60	255.90	-239.19		Strong. fresh, grey, medium grained, massive LIMESTONE. Scattered bioclastic debris
		256.90 - 257.35	22	78	0	0	256.90	-240.19		Moderately strong, black, fine to medium grained LIMESTONE - black argillite rich zones - Rubble poorly sorted fragments with some polished surfaces.
		257.35 - 259.40	3	100	68	68	257.35	-240.64		Moderately strong. black / dark grey, fine to medium grained, massive LIMESTONE. Intraclastic breccia, irregular poorly sorted limestone clasts in a black argillite rich matrix
		259.40 - 259.50	0	100	0	0	259.40	-242.69		Strong. fresh, dark grey, medium grained, massive LIMESTONE.

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Remarks

Rotary Core Log

Borehole No.
BH01
Sheet 27 of 28

Project Name: Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56	Hole Type RC
Location: Galway		Level: 16.71	Scale 1:50
Client: Galway County Council		Dates: 13/11/2015 - 21/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
		259.50 - 263.10	3	100	90	87				
		263.10 - 263.70	3	58	0	0	263.10	-246.39		Weak, black / grey MUDSTONE, running sub-parallel to core axis band is 2 - 3cm thick and partially altered to clay. The contact with the limestone shows evidence of oxidation / Fe staining
		263.70 - 266.40	2	100	100	100	263.70	-246.99		Strong. fresh, grey / pale grey, medium grained, massive LIMESTONE. Mottled and evidence of bioturbation / burrowing. 265.4 - 265.46 fracture zone with rubble and coarse brown sand
		266.40 - 267.10	17	100	40	40	266.40	-249.69		Strong. fresh, grey / pale grey, medium grained, massive LIMESTONE. Mottled and evidence of bioturbation / burrowing. Core is coated with coarse brown sand
		267.10 - 267.70	2	100	100	100	267.10	-250.39		Strong. fresh, grey / pale grey, medium grained, massive LIMESTONE. Mottled and evidence of bioturbation / burrowing.
		267.70 - 270.30	6	100	55	52	267.70	-250.99		Strong. fresh, grey / dark grey, medium grained, massive LIMESTONE. Occasional stylolitic and axial parallel joint

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Continued on next sheet

Remarks

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Rotary Core Log

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530370.59 - 728426.56
Location:	Galway		Level: 16.71
Client:	Galway County Council		Dates: 13/11/2015 - 21/12/2015

Borehole No.
BH01
Sheet 28 of 28

Hole Type
RC

Scale
1:50

Logged By
Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
		270.30 - 272.40	1	100	100	100	270.30	-253.59	▦	Strong. fresh, grey / dark grey, medium grained, massive LIMESTONE.
		272.40 - 273.40	0	0	0	0	272.40	-255.69		CAVITY no recovery
		273.40 - 274.16	5	79	39	20	273.40	-256.69	▦	Strong. fresh, very pale grey, medium grained, massive LIMESTONE. Probably a boulder within cavity / unconsolidated sediments
		274.16 - 276.70	0	8	0	0	274.16	-257.45		CAVITY - unconsolidated ground only 10% medium to coarse limestone cobbles and some gravel recovered
							276.70	-259.99		End of borehole at 276.70 m

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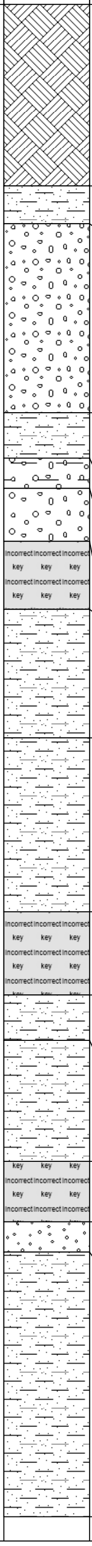
Remarks

AGS

Rotary Core Log

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Borehole No. **BH03** Sheet 1 of 11
Co-ords:	530023.82 - 728382.57		Hole Type RC
Location:	Galway		
Level:	26.26		Scale 1:50
Client:	Galway County Council		
Dates:	13/11/2015 - 09/12/2015		Logged By Dave Blaney



Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Stratum Description
									No Recovery
							1.20	25.06	Very soft, light brown, sandy CLAY with minor angular gravel
							1.45	24.81	Rubble of sub-angular to sub-rounded grey Limestone fragments and minor creamy coloured calcite. Lumps of soft light grey/brown clay. (Recovery 0.35m)
							2.70	23.56	Stiff, grey brown, sandy CLAY, occasional sub angular gravel and cobbles of dark grey limestone
							3.00	23.26	Coarse cobbles of dark grey limestone with firm / stiff grey brown sandy clay
							3.20	23.06	Coarse COBBLES with gravel. Sub-angular to sub-rounded grey / dark grey limestone with minor pink (tonalitic) granite
							3.55	22.71	Core loss
		4.15 - 4.42	C				4.00	22.26	Stiff / very stiff, light grey/brown sandy CLAY with minor (10 - 15%) scattered angular limestone gravel
							4.85	21.41	Stiff / very stiff, light grey/brown sandy CLAY with angular limestone gravel & cobbles
							6.00	20.26	Core loss
							6.55	19.71	Stiff / very stiff, light grey/brown sandy CLAY with angular limestone gravel, cobbles and occasional boulders
							6.85	19.41	Stiff / very stiff, grey / brown sandy CLAY with (12 - 20%) angular limestone gravel and occasional sub-rounded cobbles
							7.65	18.61	Core loss
							8.05	18.21	Loose angular GRAVEL with cobbles. Coated with stiff sandy clay
							8.25	18.01	Stiff / very stiff, light grey / brown, sandy CLAY, 205 sub-angular / sub-rounded gravel and occasional sub-rounded cobble and small boulder

Continued on next sheet

Remarks
All angles measured relative to core normal

Rotary Core Log

Borehole No.
BH03
Sheet 2 of 11

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530023.82 - 728382.57
Location:	Galway	Level:	26.26
Client:	Galway County Council	Dates:	13/11/2015 - 09/12/2015

Hole Type: RC
Scale: 1:50
Logged By: Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
							11.55	14.71		Stiff / very stiff, light grey / brown, sandy CLAY, 205 sub-angular / sub-rounded gravel and occasional sub-angular cobbles and small boulder
							12.94	13.32		Soft, dark chocolate brown CLAY
							12.98	13.28	incorrect key	Core Loss
		13.65 - 13.73 13.73 - 13.85	D D				13.65	12.61		Soft / very soft, greenish grey, fine sandy SILT (recovery 0.5m)
		14.90 - 15.00	D				14.75	11.51	incorrect key	Core Loss
							16.15	10.11		Soft / firm, grey / green SILT
							16.45	9.81		Soft / very soft, grey brown SILT with very thin clay laminae (Mobilised and coating surface by drilling additive)
							16.85	9.41	incorrect key	Core loss
		19.00 - 19.10 19.10 - 19.20	D D				18.60	7.66		Soft / very soft, grey SILT
		19.25 - 19.30 19.90 - 20.00	D D				19.25	7.01		Soft / firm, grey SILT, locally developed faint brown laminae (smearing of clay surface)

Continued on next sheet

Remarks
All angles measured relative to core normal

Rotary Core Log

Borehole No.	**BH03**	Sheet 3 of 11	
Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No.	Lackagh Quarry
Co-ords:	530023.82 - 728382.57	Hole Type	RC
Location:	Galway		
Level:	26.26	Scale	1:50
Client:	Galway County Council		
Dates:	13/11/2015 - 09/12/2015	Logged By	Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
									☒	
		20.95 - 21.05	D							
		21.30 - 21.40	D							
							21.70	4.56	☒	Very soft / soft, grey SILT (Recovery 50%)
							23.00	3.26	☒	Soft / firm, grey SILT (Recovery 60%)
							25.20	1.06	☒	Soft / very soft, grey SILT (Recovery 90%)
		25.50 - 25.60	D							
		25.80 - 25.90	D							
		26.50 - 26.60	D							
		26.70 - 26.80	D							
		27.20 - 27.25	D							
		27.45 - 27.55	D				27.50	-1.24	☒	Firm grey SILT with centimetric scale horizontal banding
		27.55 - 27.65	D							
							28.45	-2.19	☒	Soft, grey SILT (recovery 60%)
							30.00	-3.74		

Continued on next sheet

Remarks
All angles measured relative to core normal

Rotary Core Log

Borehole No.	**BH03**
Sheet 4 of 11	
Project Name:	Lackagh Quarry Preliminary Ground Investigation
Project No.	Lackagh Quarry
Co-ords:	530023.82 - 728382.57
Hole Type	RC
Location:	Galway
Level:	26.26
Scale	1:50
Client:	Galway County Council
Dates:	13/11/2015 - 09/12/2015
Logged By	Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
		30.25 - 30.33	D							Soft / firm grey SILT
		31.20 - 31.30	D							
		31.35 - 31.45	D							
							31.73	-5.47		Firm, grey / brown SILT
							32.40	-6.14		Soft, grey SILT
		33.70 - 33.80	D							
		33.95 - 34.03	D							
							34.60	-8.34		Soft / Firm, light grey SILT. Minor fine grained sand
		36.05 - 36.15	D				36.05	-9.79		Loose / medium dense, light grey / brown, silty SAND (recovery 30%)
		36.70 - 36.80	D							
							38.38	-12.12		Firm, dark chocolate brown organic CLAY, Small fibres bottom 0.5m of core coated with fine grained grey sand
		38.60 - 38.70	D							
		38.95 - 39.05	D							
		39.25 - 39.30	D							
		39.45 - 39.55	D							
		39.80 - 39.83	D							

Continued on next sheet

Remarks

All angles measured relative to core normal

Rotary Core Log

Project Name: Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530023.82 - 728382.57	Borehole No. **BH03** Sheet 5 of 11
			Hole Type RC
Location: Galway		Level: 26.26	Scale 1:50
Client: Galway County Council		Dates: 13/11/2015 - 09/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
		40.65 - 40.77	D				40.65	-14.39		Loose / medium dense, grey, fine to medium grained SAND (recovery 60%)
							41.00	-14.74		Firm grey / brown, organic CLAY, minor dark brown banding 0.5 - 1cm thick
		41.20 - 41.25	D							
		41.30 - 41.50	C							
		41.85 - 42.08	C				41.80	-15.54		Stiff / very stiff, dark brown, organic CLAY. Basal 4cm laminated - light / dark brown millimetric scale laminae
		42.30 - 42.35	D							
		42.35 - 42.40	D				42.40	-16.14		Firm / stiff, dark brown grey, CLAY
		42.65 - 42.97	C							
		42.97 - 43.30	C							
							43.25	-16.99		Soft to firm light grey CLAY
		44.05 - 44.20	C							
							44.20	-17.94		Core Loss
							44.85	-18.59		Firm, dark grey brown CLAY
							45.24	-18.98		Soft, grey SILT
							45.30	-19.04		Very Stiff, Dark brown / grey, organic CLAY
		46.20 - 46.27	D							
		46.27 - 46.59	C							
		47.00 - 47.10	D							
		47.20 - 47.27	D							
		47.45 - 47.55	D							
		47.85 - 48.02	C							
		48.20 - 48.30	D							
		48.45 - 48.70	C							
		49.00 - 49.10	D							
		49.30 - 49.40	D							
							50.00	-23.74		

Continued on next sheet

Remarks
All angles measured relative to core normal

Rotary Core Log

Borehole No.
BH03
Sheet 6 of 11

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords:	530023.82 - 728382.57	Hole Type RC
Location:	Galway		Level:	26.26	Scale 1:50
Client:	Galway County Council		Dates:	13/11/2015 - 09/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description
				TCR	SCR	RQD				
										Firm grey CLAY, with cobbles of strong pale grey limestone rounded to sub-angular
							50.35	-24.09		Soft, light greyish brown, cobbly CLAY, cobbles of pale grey limestone, comprise 50% of material
							51.30	-25.04		Boulder of pale grey massive limestone, stylolitic with stylolites rotated to sub-vertical orientation
							52.56	-26.30		Soft / firm, brownish grey gravelly CLAY, angular gravel (10 - 20%), sub-rounded coarse cobbles / small boulders (30 - 40%) of light grey massive limestone. (recovery 80%)
							56.40	-30.14		Sub-rounded COBBLES with coarse gravel - coated by soft light grey clay
							57.15	-30.89		Soft / firm Pale grey CLAY with angular cobbles of grey limestone (recovery 40%)
							57.85	-31.59		Soft grey brown CLAY with angular gravel and cobbles (Recovery 40%)

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Continued on next sheet

Remarks
All angles measured relative to core normal

Rotary Core Log

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Borehole No. **BH03** Sheet 7 of 11
Co-ords:	530023.82 - 728382.57		Hole Type RC
Location:	Galway	Level: 26.26	Scale 1:50
Client:	Galway County Council	Dates: 13/11/2015 - 09/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
							60.55	-34.29		BOULDER of strong, pale grey, fine to medium grained Limestone
							62.20	-35.94		Soft to firm grey brown cobbly CLAY - cobbles of angular limestone
							62.52	-36.26		Stiff brown, organic CLAY
		63.15 - 63.22	D							
		63.38 - 63.43	D							
		63.50 - 63.55	D							
		63.90 - 63.95	D							
							64.05	-37.79		Loose / medium dense, brown / grey, medium grained SAND
							64.11	-37.85		Firm / stiff, brown / dark brown, organic CLAY, Finely laminated (0.5 - 1.5mm laminae) light / dark brown. Occasional small white clay flecks / blebs. Millimetric to centimetric scale bands of fine to medium grained sand, locally developed grading - coarsening down
		64.30 - 64.35	D							
		64.90 - 64.95	D							
		65.50 - 65.60	D							
							65.78	-39.52		Stiff pale grey CLAY
							65.85	-39.59		Firm / stiff, brownish grey, finely laminated CLAY with sub-rounded cobbles of grey limestone, locally friable and broken up in situ
							66.48	-40.22		Firm grey, fine sandy CLAY, with 10% angular gravel
							66.85	-40.59		Firm, pale creamy grey, fine grained sandy CLAY (recovery 80%)
		66.95 - 67.05	D							
							67.65	-41.39		Firm, grey / creamy grey fine sandy CLAY laminated and banded texture with small clasts of creamy white, soft weather limestone
		68.40 - 68.45	D							
							69.15	-42.89		BOULDER of strong, fresh pale grey, fine grained Limestone
							69.89	-43.63		

Continued on next sheet

Remarks
All angles measured relative to core normal

Rotary Core Log

Borehole No.	**BH03**	Sheet 8 of 11	
Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No.	Lackagh Quarry
Co-ords:	530023.82 - 728382.57	Hole Type	RC
Location:	Galway		
Level:	26.26	Scale	1:50
Client:	Galway County Council		
Dates:	13/11/2015 - 09/12/2015	Logged By	Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Stratum Description
		70.40 - 70.50 70.75 - 70.85	D D						Firm, dark brown / grey, laminated CLAY, with boulders of light grey limestone
							72.98	-46.72	Soft / firm, grey / brown fine sandy CLAY with angular fine to medium grained limestone gravel and cobbles
							73.95	-47.69	Loose. light grey / brown medium grained SAND, with bands of soft brown clay (Recovery 50%)
							75.00	-48.74	BOULDER of strong, fresh, pale grey Limestone
							76.14	-49.88	Firm dark brown organic CLAY, minor coarse grained gravel
							76.35	-50.09	Soft dark brown organic CLAY - very light / low density
							76.42	-50.16	Soft light brown / grey, gravelly CLAY, 50 -60% coarse angular gravel and occasional cobbles, poor recovery of clay but all cobbles / gravel have a clay coating
							79.10	-52.84	BOULDER of strong light grey limestone
							79.54	-53.28	Soft / firm grey brown sandy CLAY, with sub-angular limestone gravel / cobbles

Continued on next sheet

Remarks
All angles measured relative to core normal

Rotary Core Log

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords:	530023.82 - 728382.57	Borehole No. **BH03** Sheet 9 of 11
Location:	Galway		Level:	26.26	Hole Type RC
Client:	Galway County Council		Dates:	13/11/2015 - 09/12/2015	Scale 1:50
					Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
							80.10	-53.84		Loose coarse gravelly COBBLES of light grey limestone. evidence of reworking by the bit
							85.55	-59.29		Tricone drilling - Open hole drilling - no recovery

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Continued on next sheet

Remarks

All angles measured relative to core normal

Rotary Core Log

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords:	530023.82 - 728382.57	Borehole No. **BH03** Sheet 10 of 11
Location:	Galway		Level:	26.26	Hole Type RC
Client:	Galway County Council		Dates:	13/11/2015 - 09/12/2015	Scale 1:50
					Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	**Coring**			Depth (m)	Level (m)	Legend	Stratum Description	
				TCR	SCR	RQD					
									incorrect key		91 92 93 94 95 96 97 98 99 100

Continued on next sheet

Remarks
All angles measured relative to core normal

Rotary Core Log

Borehole No.	**BH03**	Sheet 11 of 11		
Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530023.82 - 728382.57	Hole Type RC
Location:	Galway		Level: 26.26	Scale 1:50
Client:	Galway County Council		Dates: 13/11/2015 - 09/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
									incorrect key	
							104.95	-78.69		Strong, grey, fine to medium grained, massive LIMESTONE. Discontinuous white calcite veining dipping at 55 - 65' and up to 1cm thick., scatter bioclast debris.
							107.10	-80.84	incorrect key	Rubble of gravel sized pale grey Limestone fragments
		107.50 - 108.16	7	90	52	52	107.50	-81.24		Strong, fresh pale grey, fine grained, massive LIMESTONE. Scattered bioclastic debris, stylolitic thin argillite partings
							108.16	-81.90		Soft, dark brown CLAY, with cobbles of angular / sub-angular limestone
		108.60 - 109.90		100	100	100	108.60	-82.34		Strong, fresh, grey medium grained, massive LIMESTONE. Scattered fine bioclastic debris. 109.4m small calcite filled void with cubic crystals of purple fluorite
							109.90	-83.64		End of borehole at 109.90 m

Remarks
All angles measured relative to core normal

Rotary Core Log

Project Name: Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530150.78 - 728400.13	Borehole No. **BH04** Sheet 1 of 7
			Hole Type RC
Location: Galway		Level: 32.17	Scale 1:25
Client: Galway County Council		Dates: 11/11/2015 - 12/11/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description
				TCR	SCR	RQD				
		0.00 - 1.20		0	0	0				No Recovery sandy gravelly soil
		1.20 - 1.35		100	0	0	1.20	30.97		Mid brown, soft CLAY, with fine to medium grained, angular, limestone gravel
		1.35 - 1.50		100	0	0	1.35	30.82		Light grey to pale brown soft CLAY
		1.50 - 2.84		37	0	0	1.50	30.67		Rubble comprising - Strong, Slightly weathered pale grey fine to medium grained LIMESTONE
		2.84 - 3.36		87	13	0	2.84	29.33		Strong, fresh, pale grey to brownish grey, fine to medium grained LIMESTONE
		3.36 - 4.00		100	0	0	3.36	28.81		Strong, fresh, pale grey / brown, fine to medium grained massive LIMESTONE. Broken in chaotic angular fragments clasts ranging in size from 0.5cm to 10cm across in a matrix of firm to stiff brown / grey clay between fragments and in bands up to 10cm thick.
		4.00 - 4.20	25	100	0	0	4.00	28.17		Strong, fresh, pale grey / brown, fine to medium grained massive LIMESTONE. two fracture sets, 1. dipping at 25' Planar / Rough, 2. Dipping at 85', Planar / Rough coated with grey / brown clay.
		4.20 - 4.45		100	0	0	4.20	27.97		A rubble of Strong, fresh, pale grey / brown, fine to medium grained massive LIMESTONE.
		4.45 - 4.90	9	100	24	24	4.45	27.72		Strong, fresh, pale grey / brown, fine to medium grained massive LIMESTONE. Two fracture sets, 1. dipping at 15 -30' Planar to slightly undulating / Rough, infilled with grey /brown grey stiff clay with fine grained sand, 2. Dipping at 65', Planar / Rough
							4.90	27.27		

Continued on next sheet

Remarks
All angles measured relative to short core axis

Rotary Core Log

Borehole No.

BH04

Sheet 2 of 7

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530150.78 - 728400.13	Hole Type RC
Location:	Galway		Level: 32.17	Scale 1:25
Client:	Galway County Council		Dates: 11/11/2015 - 12/11/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description	
				TCR	SCR	RQD					
		4.90 - 5.95	10	100	10	10				Strong, fresh, pale grey / brown, fine to medium grained massive LIMESTONE. Etched, sub-horizontal stylolites. Two fracture sets, 1. Closely spaced, dipping at 15-25' Planar to slightly undulating / Rough, coated with light brown / grey clay and fine sand, 2. Dipping at 70 - 90', Planar -undulating/ Rough coated with grey / brown clay and fine grained sand.	
		5.95 - 6.20		88	0	0	5.95	26.22		Rubble of Strong, fresh, pale grey / brown, fine to medium grained massive LIMESTONE. Fragments angular and 1 - 7cm across.	6
		6.20 - 7.30	8	100	0	0	6.20	25.97		Strong, fresh, pale grey / brown, fine to medium grained massive LIMESTONE.. Slightly etched stylolites. two fracture sets, 1. dipping at 5 - 20' Planar / Rough,, grey clay infill 2. Dipping at 70 - 90', Planar - undulating / Rough coated with grey / brown clay.	7
		7.30 - 7.53	2	100	100	70	7.30	24.87		Strong, fresh, pale grey / brown, fine to medium grained massive LIMESTONE. One fracture set, dipping at 10' Planar / Rough,	
		7.53 - 7.80	7	100	0	0	7.53	24.64		Strong, fresh, pale grey / brown, fine to medium grained massive LIMESTONE. Sub-horizontal stylolites. 3 - 10cm apart. One fracture set dipping at 70 - 90' Undulating / Rough, brown clay fill - aperture width up to 2mm..	
		7.80 - 8.60	3	100	93	93	7.80	24.37		Strong, fresh, pale grey / brown, fine to medium grained massive LIMESTONE. Sub horizontal, well developed stylolites two fracture sets, 1. dipping at 5 - 10' Planar / Rough, 2. Dipping at 45', Planar / Rough no infill	8
		8.60 - 11.36	5	100	13	13	8.60	23.57		Strong, fresh, pale grey / brown, fine to medium grained massive LIMESTONE. Sub horizontal stylolites 10-20cm apart. Locally developed, sub -vertical white calcite veinlets at 9.7m. Three fracture sets, 1. dipping at 10 - 25' Undulating to Planar / Rough, locally developed light brown clay and fine grained sand, 2. Dipping at 70 - 90, Planar / Rough coated / infilled with with grey / brown clay. 3. Locally developed (between 9.4 - 97m), dipping at 85' Planar / Rough controlled by hairline white calcite veinlets	9 10

Continued on next sheet

Remarks

All angles measured relative to short core axis

Rotary Core Log

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530150.78 - 728400.13	Borehole No. **BH04** Sheet 3 of 7
Location:	Galway		Level: 32.17	Hole Type RC
Client:	Galway County Council		Dates: 11/11/2015 - 12/11/2015	Scale 1:25
				Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
									▨	
		11.36 - 12.50	8	100	72	66	11.36	20.81	▨	Strong, fresh, grey, fine to medium grained massive LIMESTONE. two fracture sets, 1. dipping at 5-15' Planar / Rough, locally developed thin clay light brown coating, 2. Dipping at 55', Planar / Rough coated with white grey calcite.
		12.50 - 15.86	1	100	100	100	12.50	19.67	▨	Strong, fresh, grey / pale grey, fine to medium grained massive LIMESTONE. Sub horizontal stylolites., minor fine bioclastic debris. One fracture set dipping at 10' Planar / Rough.

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Continued on next sheet

Remarks

All angles measured relative to short core axis

Rotary Core Log

Borehole No.	**BH04**	Sheet 4 of 7	
Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	
Co-ords:	530150.78 - 728400.13	Hole Type	RC
Location:	Galway	Level:	32.17
Scale	1:25		
Client:	Galway County Council	Dates:	11/11/2015 - 12/11/2015
Logged By	Dave Blaney		

Well	Water Strikes	Depth (m)	Type / FI	**Coring** TCR	SCR	RQD	Depth (m)	Level (m)	Legend	Stratum Description	
		15.86 - 17.74	6	100	41	41	15.86	16.31		Strong, fresh, grey, slightly mottled, fine to medium grained, massive LIMESTONE. Two fracture sets, 1. dipping at 10-25' undulating / Rough, Grey/brown to orange-brown clay coating fracture surfaces. and locally infilling fractures - aperture up to 2mm thick. 2. Dipping at 60 - 70', Planar / Rough very minor clay coating.	16 17
		17.74 - 18.40	0	100	100	100	17.74	14.43		Strong, fresh, pale grey / grey, slightly mottled, fine to medium grained, massive LIMESTONE. 5mm wide calcite vein dipping at 85'.	18
		18.40 - 18.50		100	0	0	18.40	13.77		Very soft, dark bluish grey CLAY	
		18.50 - 18.60		100	0	0	18.50	13.67		Medium strength, fresh, faintly laminated, black MUDSTONE. Disseminated, sub mm to mm scale blebs of crystalline pyrite. Basal contact has a wavy / undulating nature.	
		18.60 - 19.36	1	100	100	100	18.60	13.57		Strong, fresh, grey / dark grey, fine to medium grained, massive LIMESTONE. Faint brecciated intraclastic texture. - very irregular shaped angular, centimetric scale clasts in a dark grey fine grained matrix. Chaotic network of shaley stylolitic partings - incipient randomly orientated fracturing. One fracture set. dipping at 5' Planar / Rough, no infill	19
		19.36 - 19.55		79	0	0	19.36	12.81		Dark grey, soft CLAY with friable angular / tabular grey limestone fragments 2 - 5mm across	
		19.55 - 19.95	18	100	58	40	19.55	12.62		Strong, fresh, grey / dark grey, slightly mottled, fine to medium grained, massive LIMESTONE. Brecciated texture, angular / irregularly shaped intraclasts 0.5 - 3cm across, in a dark grey fine grained matrix (micrite), clasts are matrix	
							19.95	12.22			20

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Remarks
All angles measured relative to short core axis

Rotary Core Log

Borehole No.
BH04
Sheet 5 of 7

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords:	530150.78 - 728400.13	Hole Type RC
Location:	Galway		Level:	32.17	Scale 1:25
Client:	Galway County Council		Dates:	11/11/2015 - 12/11/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description	
				TCR	SCR	RQD					
		19.95 - 20.78	0	100	100	100	20.78	11.39		supported. One fracture set, dipping at 40-45' Planar / Rough, minor grey/brown clay. Strong, fresh, grey, slightly mottled, fine to medium grained, massive LIMESTONE. Brecciated texture, sub-angular, irregular shaped, intraclasts in a dark grey fine grained matrix. Minor bioclastic debris.	
		20.78 - 21.64	2	100	100	100	21.64	10.53		Strong, fresh, grey, fine to medium grained, massive LIMESTONE. Incipient breccia texture. Sub-horizontal stylolites 10 - 15cm apart, minor scattered bioclasts. One fracture set dipping at 25' Planar / Rough, no infill (rubbly)	21
		21.64 - 22.60	9	96	57	57	22.60	9.57		Strong, fresh, grey / pale grey, slightly mottled, fine to medium grained, massive LIMESTONE. Sub-horizontal stylolites and very small discontinuous white calcite veins. Three fracture sets, 1. dipping at 5-10' Planar to slightly stepped / Rough,. 2. Dipping at 30 - 40', Planar / Rough, 3. Dipping at 70 - 75' Planar / Rough minor orange brown clay particulary over top 20cm. .	22
		22.60 - 26.50	2	100	100	99				Strong, fresh, pale grey / brownish grey, fine to medium grained, massive LIMESTONE. Scattered small bioclasts and an occasional larger (2- 3cm) coral fragment. Sub-horizontal stylolites 20 - 30cm apart. One fracture set dipping at 5-10' Planar / Rough, minor pale brown sandy clay coating.	23 24 25

Continued on next sheet

Remarks
All angles measured relative to short core axis

Rotary Core Log

Borehole No.
BH04
Sheet 6 of 7

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530150.78 - 728400.13	Hole Type RC
Location:	Galway		Level: 32.17	Scale 1:25
Client:	Galway County Council		Dates: 11/11/2015 - 12/11/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description	
											26
		26.50 - 27.20	9	100	46	20	26.50	5.67		Strong, fresh, pale grey / brownish grey, fine to medium grained, massive LIMESTONE. Two fracture sets, 1. dipping at 5-10 Planar / Rough, no infill. 2. Dipping at 55-60', Planar / Rough, very minor yellowish brown clay coating.	27
		27.20 - 28.95	4	100	87	78	27.20	4.97		Strong, fresh, pale grey, fine to medium grained, massive LIMESTONE. Two fracture sets, 1. closely / medium spaced, dipping at 5-10' Planar / Rough, Grey/brown to orange-brown clay coating fracture surfaces. and locally infilling fractures - aperture up to 2mm thick. 2. Dipping at 45'', Planar / Rough	28
		28.95 - 29.32		0	0	0	28.95	3.22	incorrect key	CAVITY. Contacts display evidence of dissolution, pitting etc... thin coatings of yellowish brown clay	29
		29.32 - 30.20	3	100	100	100	29.32	2.85		Strong, fresh, pale grey, fine to medium grained, massive LIMESTONE. Sub-horizontal stylolites 10 - 20cm apart. One fracture set, 1. Closely spaced, dipping at 0-5' Planar / Rough,	30

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Remarks
All angles measured relative to short core axis

Rotary Core Log

Borehole No.	**BH04**
	Sheet 7 of 7
Project Name:	Lackagh Quarry Preliminary Ground Investigation
Project No.	Lackagh Quarry
Co-ords:	530150.78 - 728400.13
Hole Type	RC
Location:	Galway
Level:	32.17
Scale	1:25
Client:	Galway County Council
Dates:	11/11/2015 - 12/11/2015
Logged By	Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description	
				TCR	SCR	RQD					
		30.20 - 30.40		100	0	0	30.20	1.97		Very soft light brown / grey CLAY with a band of pale brown sand 5cm thick at top. Cavity Fill?	
		30.40 - 33.72	2	100	100	98	30.40	1.77		Strong, fresh, pale grey, fine to medium grained, massive LIMESTONE. Sub-horizontal stylolites. One fracture sets dipping at 5-20' Planar / Rough, Medium spaced.	31 32 33
		33.72 - 34.30	7	100	0	0	33.72	-1.55		Strong, fresh, pale grey, fine to medium grained, massive LIMESTONE. Sub-horizontal stylolites. Two fracture sets 1. dipping at 5-10' Planar / Rough, no infill. 2. dipping at 75-85', Planar / Rough.	34
		34.30 - 35.00	1	100	100	100	34.20	-2.03		Strong, fresh, pale grey, fine to medium grained, massive LIMESTONE. Minor sub-horizontal stylolites. One fracture sets dipping at 250' Planar to undulating / Rough, no infill.	
							35.00	-2.83		End of borehole at 35.00 m	35

Remarks
All angles measured relative to short core axis

Rotary Core Log

Borehole No.	**BH05**	Sheet 1 of 9	
Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	
Co-ords:	530186.65 - 728378.11	Hole Type	RC
Location:	Galway		
Level:	34.14	Scale	1:25
Client:	Galway County Council		
Dates:	06/11/2015 - 10/11/2015	Logged By	Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description
				TCR	SCR	RQD				
							0.40	33.74	⁘	Overburden minor cobbles recovered
		0.40 - 0.95	13	100	0	0	0.95	33.19	▦	Strong, pale grey, medium grained, massive LIMESTONE. Joint set dipping at 5 - 10' Planar / Rough, no infill. Joint set dipping at 85 - 90' Planar / Rough, grey calcite coating joint surface
		0.95 - 1.17	0	100	100	100	1.17	32.97	▦	Strong, pale grey, medium grained, massive pellety LIMESTONE
		1.17 - 1.50	12	100	0	0	1.50	32.64	▦	Strong, pale grey, medium grained, massive LIMESTONE. Joints dipping at 5 - 10' Planar - slightly undulating / Rough,, very close to closely spaced,
		1.50 - 2.30	11	100	0	0	2.30	31.84	▦	Strong pale grey / grey, medium grained, massive LIMESTONE. Joints dipping at 5 - 10' Planar / Rough. Set of two conjugate joints dipping at 85 - 90' with strike angle between sets of 110 / 70' Planar to Slightly undulating / Rough
		2.30 - 3.27	11	100	32	32	3.27	30.87	▦	Strong, pale grey, fine to medium grained, slightly bioclastic, massive LIMESTONE. Minor stylolites, Very closely to closely spaced fractures dipping at 5 - 15', Planar to slightly undulating / Rough.
		3.27 - 5.80	8	99	0	0			▦	Strong, grey / pale grey, medium grained, pellety, massive LIMESTONE. closely spaced fracture dipping at 5 - 15', Planar to slightly undulating / Rough. Fracture set dipping at 85' planar / rough

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Continued on next sheet

Remarks
All angles measured relative to short core axis

Rotary Core Log

Borehole No.
BH05
Sheet 2 of 9

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530186.65 - 728378.11	Hole Type RC
Location:	Galway		Level: 34.14	Scale 1:25
Client:	Galway County Council		Dates: 06/11/2015 - 10/11/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description	
				TCR	SCR	RQD					
		5.80 - 8.00	6	100	0	0	5.80	28.34		Strong, pale grey, medium grained, pellety, massive LIMESTONE. fine grained scattered bioclastic debris, Sub horizontal stylolites. Very closely to closely spaced fractures dipping at 5 - 20', Planar to slightly undulating / Rough, minor fine grained grey sand infill. Axial parallel conjugate jointing dipping at 85 - 90' striking 120 / 60 relative to each other. minor clay coating	6 7
		8.00 - 8.68	1	91	91	91	8.00	26.14		Strong, pale grey, medium grained, massive LIMESTONE. fine grained scattered bioclastic debris, Sub horizontal stylolites.	8
		8.68 - 9.50	11	100	88	37	8.68	25.46		Strong, pale grey, fine grained, massive LIMESTONE. Sub horizontal stylolites. Fractures dipping at 5 - 10', Planar / Rough, Fractures dipping at 45' Planar - slightly undulating / Rough	9
		9.50 - 10.25	0	100	100	100	9.50	24.64		Strong, pale grey, fine grained, massive LIMESTONE. fine, sub horizontal stylolites, spaced 5 - 10cm.	10

Continued on next sheet

Remarks
All angles measured relative to short core axis

Rotary Core Log

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530186.65 - 728378.11	Borehole No. **BH05** Sheet 3 of 9
Location:	Galway		Level: 34.14	Hole Type RC
Client:	Galway County Council		Dates: 06/11/2015 - 10/11/2015	Scale 1:25
				Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	**Coring**			Depth (m)	Level (m)	Legend	Stratum Description
				TCR	SCR	RQD				
									▦	
		10.25 - 11.34	13	100	0	0	10.25	23.89	▦	Strong, pale grey, fine grained, massive LIMESTONE. Sub horizontal stylolites. Three fractures sets 1. dipping at 5 - 10', Planar / Rough, no infill; 2. dipping at 45 - 50' planar to slightly undulating / Rough, fine sand coating fracture surfaces. 3. dipping at 85 - 90', Planar to slightly undulating / Rough cross-cutting the other fracture sets.
		11.34 - 12.62	3	100	100	78	11.34	22.80	▦	Strong, pale grey, fine to medium grained, massive LIMESTONE. Sub horizontal stylolites. Two fracture sets 1. dipping at 5 - 10', Planar to slightly undulating / Rough, 2. dipping at 85 - 90', Planar / Rough very minor iron staining.
		12.62 - 13.27	15	100	0	0	12.62	21.52	▦	Strong, pale grey / grey, fine / medium grained, massive LIMESTONE. Two fractures sets 1. Close to very closely spaced dipping at 5 - 20', Planar / Rough; 2. dipping at 70 - 80', Planar / Rough
		13.27 - 15.04	4	100	100	96	13.27	20.87	▦	Strong, grey, fine / medium grained, massive LIMESTONE. Very small scattered bioclasts, Occasional sub-horizontal stylolites. Small elongate calcite filled "Birdseyes", elongate sub vertical long axis 5 - 10mm long and 0.5mm wide. Two fracture sets 1. Medium spaced dipping at 5 - 15', Planar / Rough; 2. Widely spaced, dipping at 55', Planar / Rough

Continued on next sheet

Remarks
All angles measured relative to short core axis

Rotary Core Log

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530186.65 - 728378.11
Location:	Galway		Level: 34.14
Client:	Galway County Council		Dates: 06/11/2015 - 10/11/2015

Borehole No.	**BH05**
Sheet	Sheet 4 of 9
Hole Type	RC
Scale	1:25
Logged By	Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description	
		15.04 - 15.44	18	100	100	0	15.04	19.10		Strong, grey, fine / medium grained, massive LIMESTONE. Very small scattered bioclasts and a large 1cm dia. gastropod , Occasional sub-horizontal stylolites. Two fracture sets 1. Closely to very closely spaced dipping at 5 - 15', Planar / Rough; 2. Dipping at 85', Planar to slightly undulating / Rough	
		15.44 - 16.82	2		100	100	15.44	18.70		Strong, grey, fine / medium grained, massive LIMESTONE. Occasional sub-horizontal stylolites. Faint intraclasts centimetric scale. One fracture set dipping at 10', Planar / Rough;	16
		16.82 - 18.40	8	100	100	63	16.82	17.32		Strong, grey, fine / medium grained, massive LIMESTONE. Fine grained scattered bioclastic debris. Locally developed intraclasts, clasts are rounded to sub-rounded 1 - 2cm in dia. Two fracture sets 1. Medium spaced dipping at 10 - 15', Planar / Rough, minor associated rubble; 2. Sub-vertical - undulating dipping at 80 - 90', Planar / Rough	17 18
		18.40 - 19.26	7	100	95	60	18.40	15.74		Strong, grey, fine grained, massive LIMESTONE. Thin band of coarse brachiopod shells at 18.82m. Two fracture sets 1. Medium spaced, dipping at 10', Planar / Rough, minor light brown clay coating the fracture surfaces; 2. Dipping at 80-85', Planar / Rough associated with thin white calcite veinlets	19
		19.26 - 19.95	3	100	100	100	19.26	14.88		Strong, pale grey, fine / medium grained, massive, pellety LIMESTONE. Fine scattered bioclasts, Occasional sub-horizontal stylolites. Fracture set dipping at 5 - 10', Planar / Rough, no infill.	
							19.95	14.19			20

Continued on next sheet

Remarks
All angles measured relative to short core axis

Rotary Core Log

Borehole No.	**BH05**	Sheet 5 of 9	
Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No.	Lackagh Quarry
Co-ords:	530186.65 - 728378.11	Hole Type	RC
Location:	Galway	Level:	34.14
Scale	1:25		
Client:	Galway County Council	Dates:	06/11/2015 - 10/11/2015
Logged By	Dave Blaney		

Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Stratum Description
19.95 - 20.20	24	100	60	0	20.20	13.94	Strong, grey, fine / medium grained, massive LIMESTONE. Two fracture sets 1. Closely spaced dipping at 5 - 10', Planar / Rough; 2. Dipping at 45', Planar / Rough light brown clay infill, up to 2mm thick.
20.20 - 20.30	0	0	0	0	20.30	13.84	Core loss
20.30 - 20.45	0	100	100	100	20.45	13.69	Very stiff, light brown / orange brown CLAY. Finely laminated.
20.45 - 20.75	20	100	0	0	20.75	13.39	Strong, grey, fine / medium grained, massive LIMESTONE. Small black millimetric scale blebs- burrowing? Three fracture sets 1. Very closely spaced, dipping at 5', Planar / Rough; 2. Dipping at 80', Planar / Rough with white calcite coating fracture surfaces. 3. dipping at 70', undulating / rough crosscut by set 2.
20.75 - 21.50	9	100	35	24	21.50	12.64	Strong, grey pale grey mottled, fine / medium grained, massive, pellety LIMESTONE. Intraclastic texture sub-angular to sub-rounded clasts 1 - 2cm dia. in a darker grey fine grained matrix. Two fracture sets 1. Dipping at 10 - 15', Planar / Rough; 2. Dipping at 60', Planar to undulating / Rough, fracture surfaces coated with light brown clay
21.50 - 22.40	4	100	94	94	22.40	11.74	Strong, grey, medium grained, massive LIMESTONE. Very small scattered bioclasts with occasional coarse brachiopods. Minor sub-horizontal stylolites. Two fracture sets 1. Medium spaced dipping at 10', Planar / Rough; 2. Medium spaced, dipping at 35', Planar / Rough
22.40 - 23.73	5	100	16	16	23.73	10.41	Strong, pale grey, fine / medium grained, massive LIMESTONE. Occasional sub-horizontal stylolites with minor oxidation. Thin hairline, steeply dipping white calcite veinlets. Two fracture sets 1. Medium spaced dipping at 5 - 10', Planar / Rough; 2. Dipping at 80-85', Planar / Rough, light brown clay coating fracture surfaces, locally developed fracture infill up to 1mm thick
23.73 - 25.55	2	100	93	93			Strong, grey / grey brown, fine / medium grained, massive LIMESTONE. Occasional faint, sub-horizontal stylolites. Minor scatter fine bioclastic debris. Two fracture sets 1. Medium spaced dipping at 5 - 10', Planar / Rough; 2. Dipping at 60', Planar / Rough

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Remarks
All angles measured relative to short core axis

Rotary Core Log

Borehole No.	**BH05**	Sheet 6 of 9
Project Name:	Lackagh Quarry Preliminary Ground Investigation	
Project No.	Lackagh Quarry	
Co-ords:	530186.65 - 728378.11	
Hole Type	RC	
Location:	Galway	
Level:	34.14	
Scale	1:25	
Client:	Galway County Council	
Dates:	06/11/2015 - 10/11/2015	
Logged By	Dave Blaney	

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description	
				TCR	SCR	RQD					
		25.55 - 25.85	13	100	80	80	25.55	8.59		Strong, grey / brownish grey, fine / medium grained, massive LIMESTONE. Very small scattered bioclasts, Two fracture sets 1. dipping at 10 - 20', Planar / Rough; 2. Dipping at 50', Planar / Rough no infill	
		25.85 - 26.60	3	100	91	91	25.85	8.29		Strong, grey, fine / medium grained, massive LIMESTONE. Slightly oxidised sub-horizontal stylolites. Fracture set dipping at 5 - 10', Planar / Rough; no infill	26
		26.60 - 27.65	9	100	37	37	26.60	7.54		Strong, pale grey / brownish grey, fine / medium grained, massive LIMESTONE. Occasional thick shelled bioclasts - brachiopod, Three fracture sets 1. Dipping at 10 - 20', Planar / Rough; 2. Close spaced, dipping at 55 - 60', Planar / Rough; 3. Dipping at 85', Planar / Rough minor white calcite coating fracture surfaces	27
		27.65 - 28.03	3	100	100	100	27.65	6.49		Strong, pale grey / brownish grey, fine / medium grained, massive LIMESTONE. Occasional sub-horizontal stylolites. Fracture set dipping at 5 ', Planar / Rough, no infill	28
							28.03	6.11		Strong, pale grey / brownish grey, fine / medium grained, massive LIMESTONE. Three fracture sets 1. Close spaced dipping at 5 - 20', Planar / Rough; 2. Widely spaced, dipping at 40-50', Planar / Rough, at 31.7m light brown clay infill 1mm thick; 3. Axial parallel - 90', crosscuts all the other fracture sets. Planar / rough with a thin coating of white calcite.	29 30

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Remarks

All angles measured relative to short core axis

Rotary Core Log

Borehole No.
BH05
Sheet 7 of 9

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530186.65 - 728378.11	Hole Type RC
Location:	Galway		Level: 34.14	Scale 1:25
Client:	Galway County Council		Dates: 06/11/2015 - 10/11/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description	
		28.03 - 32.03	3	100	0	0					31
		32.03 - 34.72	4	100	100	97	32.03	2.11		Strong, pale grey / brownish grey, fine / medium grained, massive LIMESTONE. Occasional sub-horizontal stylolites. One fracture set, close to Medium spaced, dipping at 5 - 20', Planar / Rough, no infill.	32 33 34
							34.72	-0.58		Strong, grey . brownish grey, fine / medium grained, massive LIMESTONE. Very small scattered bioclasts, and a rare thick shelled	35

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Remarks
All angles measured relative to short core axis

Rotary Core Log

Borehole No.
BH05
Sheet 8 of 9

Project Name: Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530186.65 - 728378.11	Hole Type RC
Location: Galway		Level: 34.14	Scale 1:25
Client: Galway County Council		Dates: 06/11/2015 - 10/11/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description	
				TCR	SCR	RQD					
		34.72 - 37.20	6	100	4	4	37.20	-3.06		brachiopod . Occasional sub-horizontal stylolites. Three fracture sets 1. Close spaced dipping at 10 - 20', Planar / Rough; 2. Very widely spaced, dipping at 35-40', Planar / Rough; 3. 75 - 85' Undulating / rough, fracture surface coated with light brown clay. Crosscuts other fracture sets	36 37
		37.20 - 38.00	0	100	100	100	38.00	-3.86		Strong, grey / pale grey, fine / medium grained, massive LIMESTONE.	38
		38.00 - 40.00		100	0	0				Strong, pale grey, fine to medium grained, massive LIMESTONE. Occasional stylolites, two fracture sets. 1. dipping at 5', planar / rough , 2. dipping at 85-90' Planar / rough coated and partially infilled by light brown clay	39 40

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Remarks
All angles measured relative to short core axis

Rotary Core Log

Borehole No.
BH05
Sheet 9 of 9

Project Name: Lackagh Quarry Preliminary Ground Investigation
Project No. Lackagh Quarry
Co-ords: 530186.65 - 728378.11
Hole Type RC
Location: Galway
Level: 34.14
Scale 1:25
Client: Galway County Council
Dates: 06/11/2015 - 10/11/2015
Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring			Depth (m)	Level (m)	Legend	Stratum Description	
				TCR	SCR	RQD					
							40.30	-6.16		End of borehole at 40.30 m	
											41
											42
											43
											44
											45

Remarks
All angles measured relative to short core axis

Rotary Core Log

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530125.14 - 728383.08	Borehole No. **BH06** Sheet 1 of 5
Location:	Galway		Level: 30.80	Hole Type RC
Client:	Galway County Council		Dates: 10/12/2015 - 18/12/2015	Scale 1:50
				Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
										TOPSOIL
							0.10	30.70		Soft, pale grey, sandy CLAY (Recovery 35%)
							1.05	29.75		Loose grey to dark grey cobbly BOULDERS of bioclastic limestone, minor pale grey sandy clay
							1.50	29.30		Firm, light yellowish brown, sandy CLAY, coarse grained sub-angular cobbles of dark grey limestone and occasional granite cobble (recovery 45%)
							3.10	27.70		Very stiff , light yellowish brown sandy CLAY with coarse gravel / cobbles and occasional boulders of sub-rounded to sub-angular limestone with minor granite
		5.25 - 5.50	C							
							7.91	22.89		Firm / stiff light grey CLAY
							7.96	22.84		Very stiff, light brown sandy CLAY with minor light orange oxidation spots / patches. Coarse gravel / cobbles and occasional boulders of sub-rounded to sub-angular limestone with minor granite
		9.95 - 10.20	C							

Continued on next sheet

Remarks
All angles measured relative to short core axis

Rotary Core Log

Borehole No.
BH06
Sheet 2 of 5

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530125.14 - 728383.08
Hole Type	RC		
Location:	Galway	Level:	30.80
Scale	1:50		
Client:	Galway County Council	Dates:	10/12/2015 - 18/12/2015
Logged By	Dave Blaney		

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
							15.20	15.60		Loose, medium grained angular clayey GRAVEL with small cobbles all coarse fragments coated with sticky, soft, dark grey clay
							15.93	14.87		Very Stiff dark grey / brown CLAY
		16.20 - 16.50	C							
		16.60 - 16.70	D							
		16.70 - 16.80	D							
		17.13 - 17.20	D							
		18.00 - 18.25	C				18.00	12.80		Very Stiff grey CLAY
		18.25 - 18.35	D							
		18.65 - 18.75	D							
		18.95 - 19.05	D							
		19.70 - 19.95	C							
		20.00 - 20.25	C							

Continued on next sheet

Remarks
All angles measured relative to short core axis

Rotary Core Log

Borehole No.
BH06
Sheet 3 of 5

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530125.14 - 728383.08
Hole Type	RC		
Location:	Galway	Level:	30.80
Scale	1:50		
Client:	Galway County Council	Dates:	10/12/2015 - 18/12/2015
Logged By	Dave Blaney		

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
							21.20	9.60		Firm grey CLAY
		21.45 - 21.52 21.52 - 21.60	D D				21.48	9.32		Firm / Stiff finely laminated dark brown / brown CLAY
							21.82	8.98		Firm, dark brown CLAY with 60% tabular angular gravel
							21.92	8.88		Firm grey fine sandy CLAY with angular limestone gravel and some coarse cobbles and small boulders
							22.60	8.20		Very soft, light grey sandy CLAY with rounded gravel
							22.84	7.96		Soft, grey sandy CLAY angular gravel / cobbles
							23.30	7.50		Firm / Stiff grey sandy CLAY with sub-angular / angular matrix supported coarse gravel and cobbles
							23.60	7.20		Soft, grey, sandy CLAY with medium / coarse grained, angular gravel and an occasional boulder (25cm dia.
							25.50	5.30		Soft / firm grey / green sandy CLAY with sub angular cobbles and boulders. Some of the clay is washed out and is just coated the cobbles and boulders
							26.65	4.15		Stiff / very stiff, light grey CLAY occasional boulder of pale grey limestone
							27.30	3.50		Loose, grey / dark grey cobbly GRAVEL with occasional boulders of limestone coated with very soft brownish grey clay

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Continued on next sheet

Remarks
All angles measured relative to short core axis

Rotary Core Log

Borehole No.
BH06
Sheet 4 of 5

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Co-ords: 530125.14 - 728383.08	Hole Type RC
Location:	Galway		Level: 30.80	Scale 1:50
Client:	Galway County Council		Dates: 10/12/2015 - 18/12/2015	Logged By Dave Blaney

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description	
							30.85	-0.05		Soft / very soft, pale grey / greenish grey bouldery CLAY, cobbles and coarse gravel, clay washed out and just left coating fragments in some areas.	31 32 33
							33.20	-2.40		Firm greenish grey (Khaki) CLAY with angular coarse cobbles of pale grey limestone	
							33.50	-2.70		Firm, greenish grey gravelly CLAY, gavel composed of dark grey limestone	
							33.70	-2.90		Pale grey, medium grained, fresh, massively bedded limestone BOULDER Broken up along a series of fractures - undulating rough dipping at 70-80' and planar rough dipping at 50-60'. Minor grey clay coating joint surfaces.	34
							34.70	-3.90		Loose sub-angular COBBLES coated with soft pale grey clay	35
							35.10	-4.30		Soft greenish grey sandy, gravelly CLAY with angular cobbles and small boulders of pale grey / occasionally black limestone	36 37 38 39
							39.10	-8.30		Loose sub-angular COBBLES of very dark grey limestone (Recovery 30%)	40

Continued on next sheet

Remarks
All angles measured relative to short core axis

Rotary Core Log

Project Name:	Lackagh Quarry Preliminary Ground Investigation	Project No. Lackagh Quarry	Borehole No. **BH06** Sheet 5 of 5
Co-ords:	530125.14 - 728383.08	Hole Type	RC
Location:	Galway	Level:	30.80
Scale	1:50		
Client:	Galway County Council	Dates:	10/12/2015 - 18/12/2015
Logged By	Dave Blaney		

Well	Water Strikes	Depth (m)	Type / FI	Coring TCR	Coring SCR	Coring RQD	Depth (m)	Level (m)	Legend	Stratum Description
							40.60	-9.80		Loose, coarse gravelly COBBLES, angular to sub-angular with some coated by greenish grey clay occasional small boulder
							44.40	-13.60		BOULDER of strong, fresh, fine / medium grained, massively bedded Limestone. 44.8m a joint filled with soft, dark grey clay, 2cm thick (Possibly bedrock)
							45.00	-14.20		End of borehole at 45.00 m

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Remarks
All angles measured relative to short core axis

Appendix C

Lackagh Tunnel Geological and Hydrogeological Appraisal

Galway County Council

N6 Galway City Ring Road

Lackagh Tunnel: Geotechnical and Hydrogeological Appraisal

GCOB-4.03-4.16

Issue | 23 June 2017

Job number 233985-00

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			Prepared by	Checked by	Approved by
		Name	Les Brown, Juli Crowley, Marie Fleming, Sean Ross & Paul Sweeney	Mary Hurley, Fiona Patterson, Matt Sykes (Director UK Tunnels Arup)	Eileen McCarthy
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		Name			
		Signature			

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Contents

Appendices

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EXTRACT

Tunnel Bore Separation

Appendix E

Drill and blast assessment

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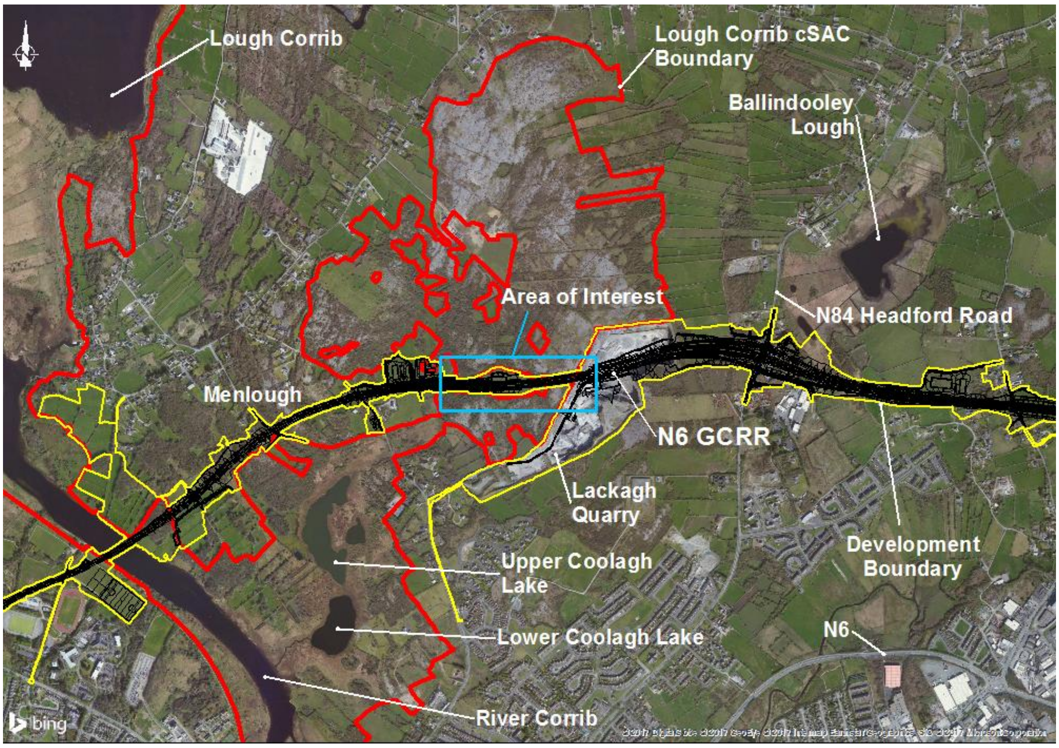
EXTRACT

1 Introduction

As part of the N6 Galway City Ring Road, hereafter referred to as the proposed road development, a mined twin tunnel is proposed east of Menlough and west of Lackagh Quarry, Lackagh Tunnel. The western approach to the tunnel lies partly within Lough Corrib candidate Special Area of Conservation (cSAC), with the tunnel itself passing beneath this cSAC. The tunnel exits through the western boundary of Lackagh Quarry (which has been inactive since 2010) at its eastern portal. Refer to **Figure 1.1**.

Figure 1.1: Overview of the Area of Interest



There are a number of Qualifying Interest (QI) Annex I habitats within Lough Corrib cSAC which are located above, immediately adjacent to, or in close proximity to the proposed road development, some of which are groundwater dependent. The proposed road development tunnels beneath the Lough Corrib cSAC from the western face of Lackagh Quarry in a westerly direction and then enters a cutting which runs adjacent to the Lough Corrib cSAC boundary.

Construction and operation of Lackagh Tunnel and the Western Approach has the potential to directly and indirectly impact these sensitive ecological habitats. The purpose of this report is to appraise the hydrogeological and geotechnical aspects of the design, construction and operation of Lackagh Tunnel and its approaches.

The report describes the hydrogeological and geotechnical existing environmental features (constraints[1]) and potential direct and indirect impacts[2] on these features. These include the Annex I habitats located at the surface above the proposed tunnel, namely priority Annex I Limestone pavement [*8240] habitat and Annex I Calcareous grassland [*6210/6210] and the groundwater catchments within this area which support groundwater dependant terrestrial ecosystems (GWDTE); including Coolagh Lakes and Ballindooley Lough. Ballindooley Lough includes supporting habitat for birds listed as Special Conservation Interests (SCIs) of Lough Corrib Special Protection Area (SPA) and Inner Galway Bay SPA. This report also outlines the design measures incorporated into the proposed road development to avoid potential direct and indirect impacts and mitigation measures for the construction and operation of the proposed tunnel.

The focus of this report is an assessment of the hydrogeological and geotechnical aspects of the design, construction and operation of Lackagh Tunnel. Potential environmental direct and indirect impacts not effecting the hydrogeological or geotechnical environment are assessed in the relevant sections of the NIS and EIA Report.

Chapter 2 of this report describes the proposed works at Lackagh Tunnel. **Chapter 3** describes the receiving hydrogeological and geological environment and identifies the hydrogeological and geotechnical constraints and also includes the ground investigation (GI) data. **Chapter 4** identifies the potential direct and indirect impacts to the hydrogeological and geotechnical constraints as a result of the proposed road development at Lackagh Tunnel and the immediate approaches. **Chapter 5** presents the design avoidance and mitigation measures required during construction and operation to prevent or address potential direct or indirect impacts to the hydrogeological and geotechnical constraints based on scientific data. Finally, **Chapter 6** summarises the report findings, with a conclusion in **Chapter 7**.

---

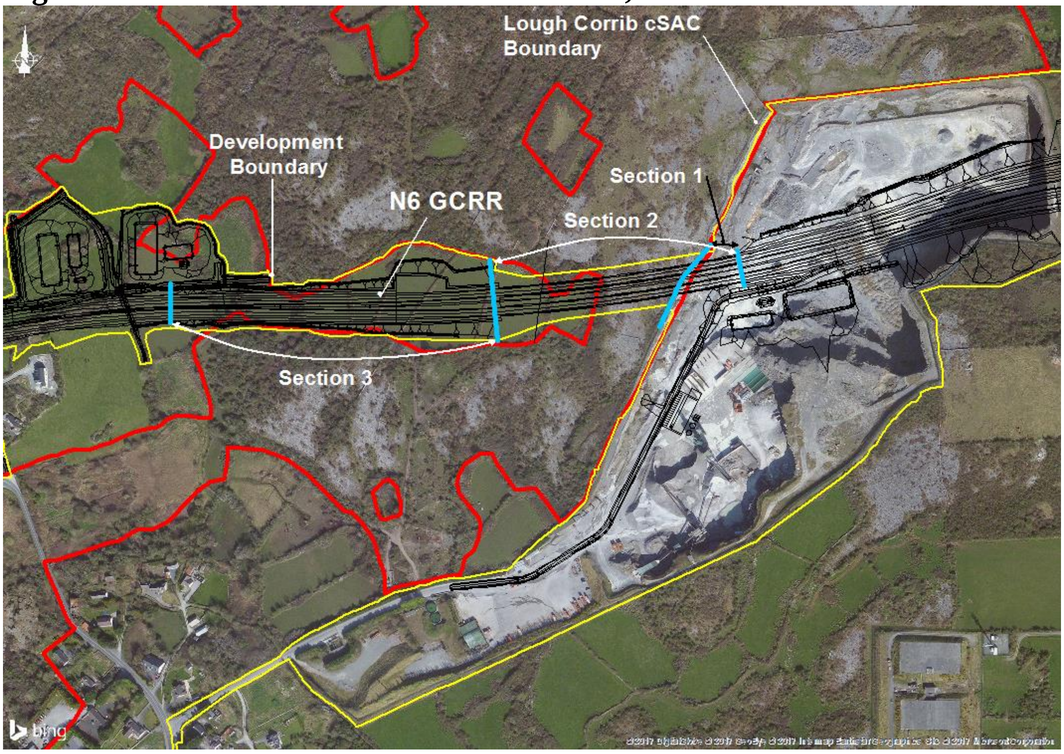
[1] Constraints are hydrogeological and geotechnical environmental features

[2] Potential direct and indirect impacts are the potential impacts that the proposed road development could have on a particular feature/constraint

2 Lackagh Tunnel Description

For the purpose of this report the assessment of the design, construction and operation of Lackagh Tunnel is split into three areas, namely Section 1 (Lackagh Quarry Face), Section 2 (Lackagh Tunnel) and Section 3 (Western Approach), hereafter referred to as Sections 1, 2 and 3 and are shown in Figure 2.1 below. A combined assessment of the potential hydrogeological and geotechnical direct and indirect impacts for Sections 1, 2 and 3 are presented in **Sections 4.4** and **5.4** of the report.

Figure 2.1: Aerial view of the three Sections 1, 2 and 3



Section 1, Lackagh Quarry Face, includes the stabilisation of the western quarry face and the construction of the eastern tunnel portal. Section 2, Lackagh Tunnel, includes a mined twin bore tunnel in rock constructed using a drill and blast methodology. There is a cross over between Sections 1 and 2 as the tunnel extends into Lackagh Quarry. The eastbound tunnel is approximately 20m longer than the westbound tunnel as a result of the existing topography on entering Lackagh Quarry. Section 3, the Western Approach, includes the construction of the western tunnel portal (where the underlying ground conditions change from rock to overburden) and retaining systems to support the cut face between the existing ground level and proposed road level. In Section 3 the proposed road development lies partially within the Lough Corrib cSAC and in close proximity to Qualifying Interest (QI) Annex I habitat. Refer below to **Table 2.1** and **2.2** for Section and tunnel details.

The tunnel entry portals extend from existing bedrock and are located between chainages:

- Eastbound tunnel:

  - Eastern entry portal Ch. 11+150 to 11+180
  - Western entry portal Ch. 11+390 to 11+420
- Westbound tunnel:
  - Eastern entry portal Ch. 11+150 to 11+180
  - Western entry portal Ch. 11+375 to 11+400

Lough Corrib cSAC is located immediately west of Section 1. Section 2 tunnels beneath Lough Corrib cSAC, including the Annex I habitat, between approximately CH.11+240 and 11+350. Section 3 lies partially within the Lough Corrib cSAC and traverses between Annex I habitat which is located north and south of the proposed road development. In this section the proposed development overlaps with the Lough Corrib cSAC boundary, but does not impact directly on any QI or Annex I habitat, between approximately Ch. 10+830 and Ch. 11+020 to the south and Ch. 10+880 and 10+950 to the north, refer to **Figure 2.2** and **Appendix B**

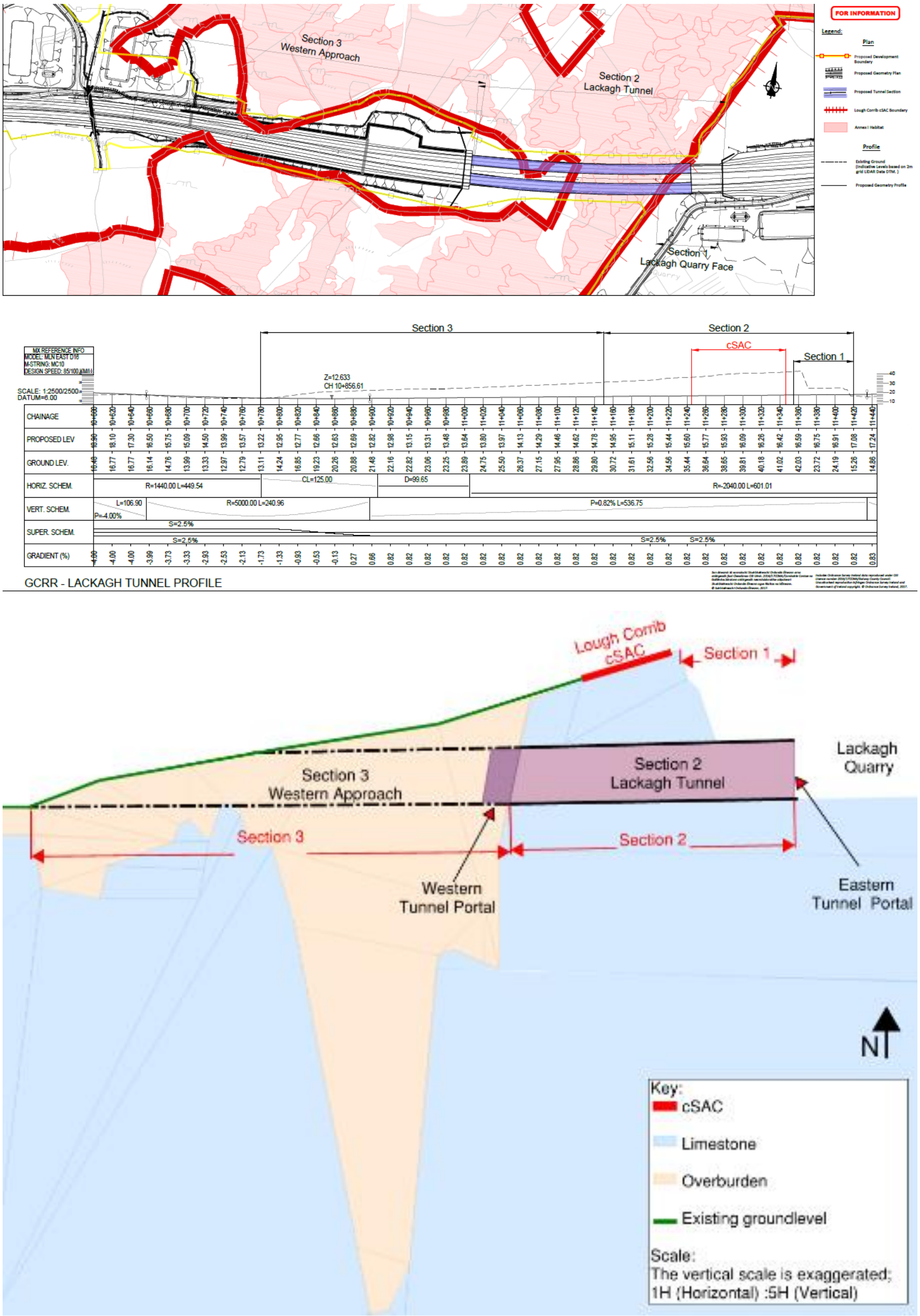
Table 2.1: Summary of the Section details

Section	**Chainage**		**Approximate Section Length**	**Proposed finished road level (range in mOD)**	
	From	**To**		**Minimum**	**Maximum**
1	11 +390	11 +420	30	+16.5	+17.0
2	11 +180	11 +420	240	+14.8	+17.0
3	10 +775	11 +180	405	+12.7	+14.8

Table 2.2: Summary of Tunnel Details

Tunnel bore	**Approximate Chainage**		**Approx. Tunnel Length**	**Approximate chainage of mined and blast tunnel in rock**		**Approx. length of tunnel in rock**
	From	**To**		**From**	**To**	
Eastbound (North)	11+150	11+420	270	11+180	11+390	21
Westbound (South)	11+150	11+400	250	11+180	11+375	195

Figure 2.2: Plan, profile and schematic cross section of Section 1-3



3 Receiving Environment

3.1 Introduction

This chapter of the report identifies the receiving hydrogeological and geotechnical environment (constraints) which is of relevance to the design, construction and operation of Lackagh Tunnel and its approaches, i.e. Sections 1 2 and 3. The potential direct and indirect impacts to the hydrogeological and geotechnical constraints are presented in **Chapter 4.**

3.2 Background

The proposed road development lies within the regional vicinity of four European sites. These European sites are listed as follows:

- Lough Corrib cSAC
- Lough Corrib SPA
- Galway Bay Complex cSAC
- Inner Galway Bay SPA

Of these four European sites, the proposed road development traverses the Lough Corrib cSAC, refer to **Figure 3.1**.

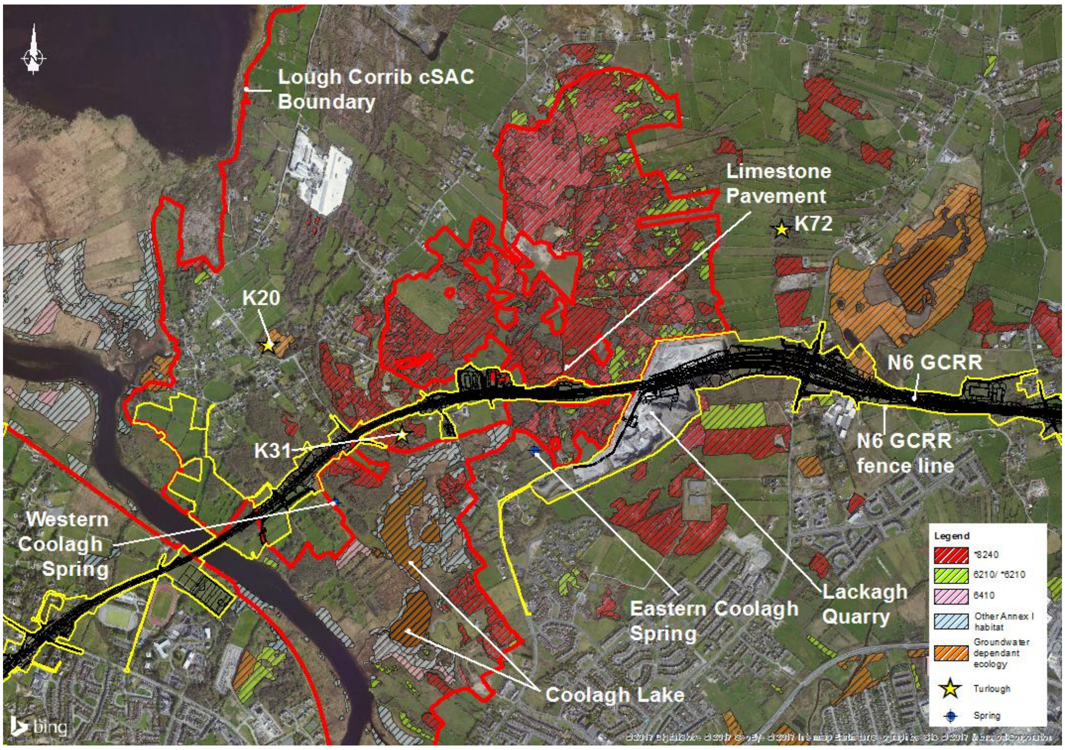
Based on the hydrogeological assessment, there are two groundwater bodies (GWB) that are directly traversed by the proposed road development at Lackagh Tunnel namely the Lough Corrib Fen 1 GWB and the Clare-Corrib GWB (refer to **Figure 3.11** and **Appendix F Hydrogeology Figure 5.02**). Lough Corrib Fen 2 GWB lies adjacent to Lackagh Tunnel. These two groundwater bodies contribute directly to Lough Corrib cSAC. Lough Corrib Fen 2 GWB also contributes to Lough Corrib SPA. As the River Corrib flows into Galway Bay these three GWBs also contribute indirectly to Galway Bay Complex cSAC and Inner Galway Bay SPA.

As discussed in **Chapter 1** and **2**, the Western Approach to the Lackagh Tunnel lies partly within Lough Corrib cSAC, with the tunnel itself passing beneath the cSAC. The Coolagh Lakes, located to the south west of Lackagh Quarry, which also form part of the Lough Corrib cSAC, are groundwater dependant terrestrial ecosystems (GWDTE). There are groundwater flow paths between the Coolagh Lakes and the groundwater bodies (GWB) in the vicinity of the proposed Lackagh Tunnel. Furthermore, Ballindooley Lough, located 1.1 km to the north east of the proposed Lackagh Tunnel is used by bird species listed as Special Conservation Interests (SCIs) of Lough Corrib SPA (which is located 1.8km North West of Lackagh Tunnel) and of Inner Galway Bay SPA.

Galway Bay Complex cSAC and Inner Galway Bay SPA lie 2.5km south of Lackagh Tunnel. The regional groundwater regime in the area discharges to the Coolagh Lakes, the River Corrib, and Galway Bay. Therefore groundwater contributes indirectly to Galway Bay Complex cSAC and Inner Galway Bay SPA.

The ecology in the area of the proposed tunnel sensitive to potential hydrogeological and geological direct and indirect impacts include Limestone pavement, Calcareous grassland and GWDTE (including Turloughs and Coolagh Lakes) - refer to **Figure 3.1**. Groundwater contributes to Coolagh Lakes, Lough Corrib, River Corrib and Galway Bay. GWDTE and Limestone pavement are sensitive to changes in hydrogeology but are dependent on different aspects of the water environment. Whilst, GWDTE is dependent on the groundwater table and its interaction with surface water, Limestone pavement habitat is dependent on exposed, free draining and unsaturated limestone with clints and grykes.

Figure 3.1: Limestone pavement and GWDTE adjacent to Lackagh Tunnel



An overview of the topography is given in **Section 3.3**, the existing hydrogeological and geotechnical environment in **Section 3.4** and **3.5** respectively and a description of the ground model in **Section 3.6** of the report.

3.3 Topography

3.3.1 Section 1: Lackagh Quarry Face

The proposed eastern tunnel entry portal is located within the now inactive Lackagh Quarry, on the western quarry wall. The western quarry wall comprises of a lower and upper bench. The lower bench floor level is at +15mOD which rises steeply to +24mOD at the upper bench with a slope angle ranging from 75 degrees to sub-vertical in places with an uneven surface, (**Figure 3.2**). The distance between the top of the lower bench to the base of the upper bench ranges in width from 28m to 40m around the proposed tunnel portal area, (**Figure 3.3**). The upper bench ranges in height from 18m to 20m with a slope angle ranging from 70 degrees to sub-vertical. The maximum elevation of the quarry wall in this location is +44mOD.

Figure 3.2: Section 1 – Aerial view of Lackagh Quarry and the eastern tunnel portal

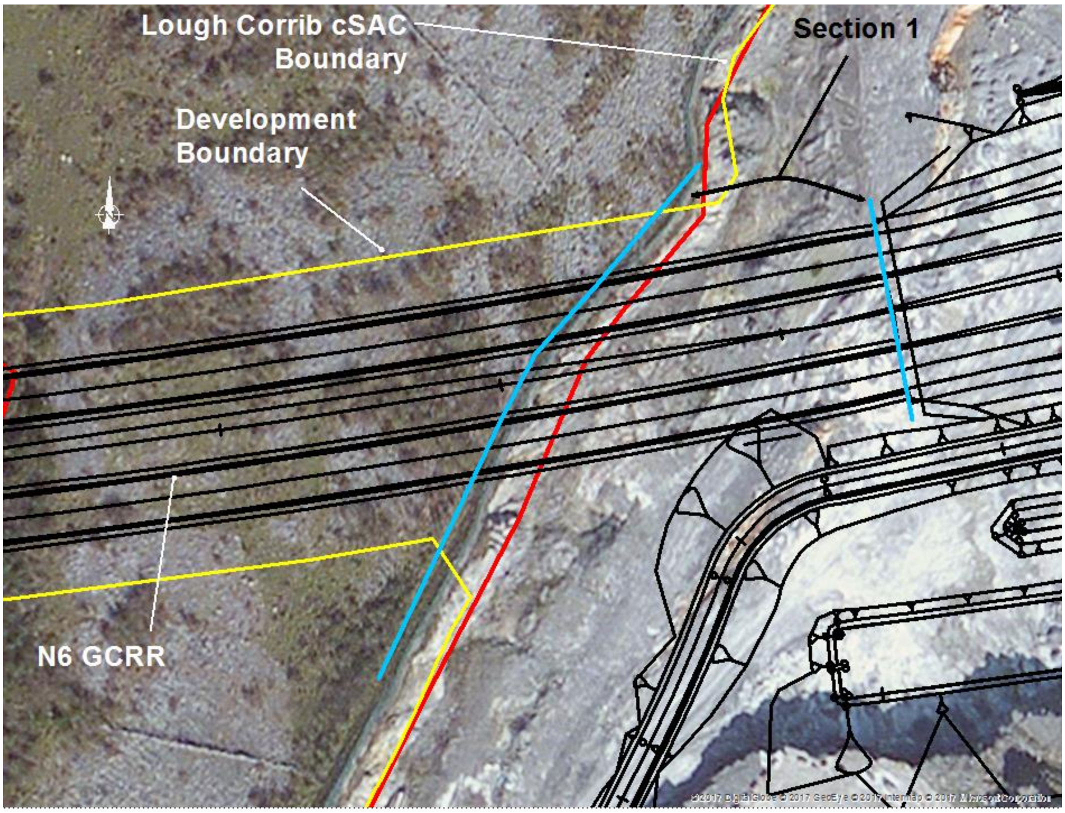
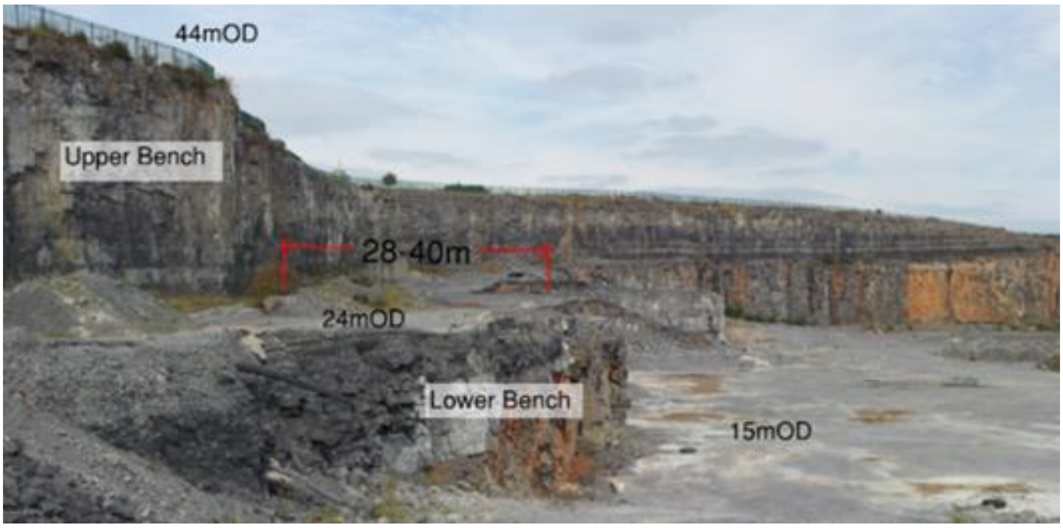


Figure 3.3: Photograph of Lackagh Quarry in the vicinity of the tunnel portal

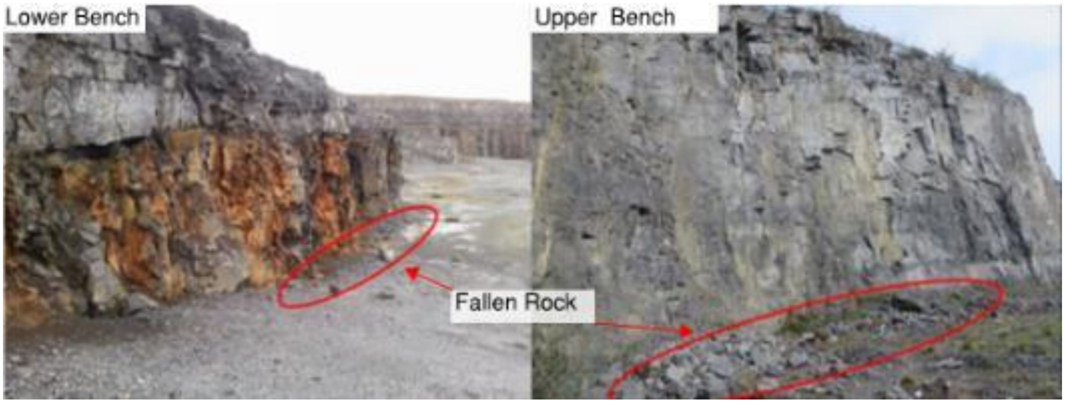


The quarry boundary is defined by a steel fence on a concrete plinth, which borders the Limestone pavement within the Lough Corrib cSAC. There is an average distance of approximately 1m between the edge of the fenceline plinth and the top of the upper quarry bench. **Figure 3.4** below shows a view of the western quarry wall from a distance, outlining the lower and upper bench and boundary fence.

Figure 3.4: Features of the eastern tunnel portal area, with extent of tunnel portal marked within red rectangle

Some instability in the rock face is evident predominantly from blast damage during the operation of the quarry, with open discontinuities (joints and fractures), loose rock and the accumulation of debris resulting from spalling and failures present at the base of the lower and upper benches, see **Figure 3.5** below.

Figure 3.5: Face instability on the lower and upper bench



3.3.2 Section 2: Lackagh Tunnel

Section 2 focuses on Lackagh Tunnel which overlaps with Sections 1 as the tunnel extends into Lackagh Quarry, **Figure 3.6**. The proposed tunnel lies beneath Limestone pavement within the Lough Corrib cSAC and beneath agricultural fields. The existing ground levels of the Limestone pavement, **Figure 3.7**, range from 36.4 to +40.5mOD along the alignment of the proposed road development, falling from east to west. The tunnel extends west beyond the Limestone pavement extents, in an area overlain by agricultural land where the ground level reduces to +30.7mOD in the west from +36.4mOD in the east.

Figure 3.6: Section 2 – Lackagh Tunnel Footprint

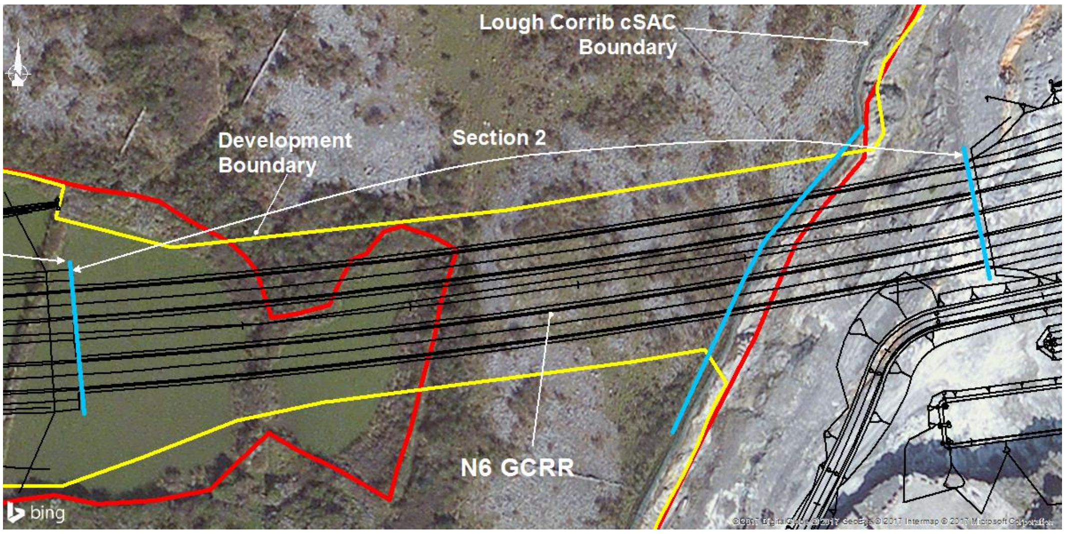


Figure 3.7: Photographs of Limestone pavement located in Section 2

3.3.3 Section 3: Western Approach

Section 3 is bounded on the north and south by Lough Corrib cSAC and is located in an area made up of agricultural fields and stone boundary walls, **Figure 3.8**. The existing ground levels fall from east to west from +30.7 to +13.41mOD.

Figure 3.8: Section 3 – Western Approach

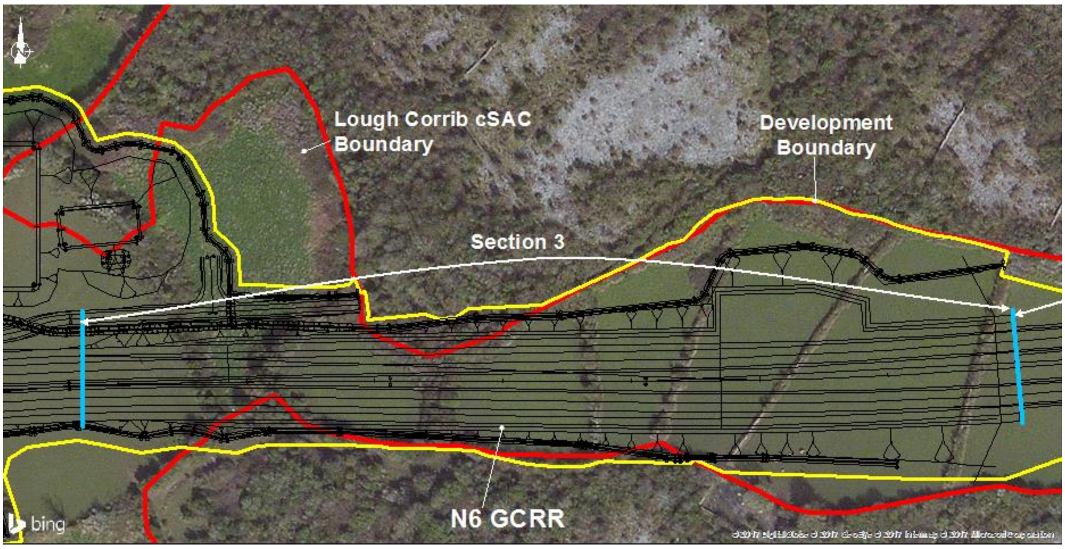


Figure 3.9: Photographs of the agricultural fields located in Section 3

3.4 Existing Hydrogeological Environment

3.4.1 Introduction

This section of the report presents an overview of the existing hydrogeological environment including groundwater dependant terrestrial ecosystems (GWDTE) and Limestone pavement, groundwater data collection and an interpretation of the groundwater data in the areas of Coolough, Menlough and Lackagh Quarry.

3.4.2 Overview

To understand the existing hydrogeological environment investigations including a desk study, walkovers, site surveys and ground investigations were undertaken.

The karst survey undertaken for the constraints study for the proposed road development included a site walkover. The survey identified several karst features in the area including the Western and Eastern Coolagh Springs, which discharge to Upper Coolagh Lake, as well as three Turloughs in the Menlough/Coolough area (Refer to **Figure 3.1**).

From site walkovers the ground surface in this area is found to almost entirely comprise of limestone, whilst in a number of areas there is no rock outcrop and clayey subsoils dominate, such as beneath the agricultural fields in Sections 2 and 3.This includes areas at Terryland, where the Terryland River flows along a wide flat valley floor of clayey subsoils and at Coolough where the lakes lie on a wide flat low lying area with clayey soils and subsoils.

As part of the ground investigation (GI), undertaken for the proposed road development, areas with clay subsoils were examined by geophysics (resistivity) surveying and borehole drilling. In a number of locations, such as the Western Approach to Lackagh Tunnel, Section 3, these clayey areas were proven to be deep buried karst features that have been in filled by sediment deposition. These features are particularly deep, with the feature at the western approach to Lackagh Tunnel having a depth of 104.95m (to -78.69mOD). Adjacent features at Lackagh Quarry were proven by geophysics to be greater than 30m deep (to > -20mOD) and are also considered to be buried karst features.

These buried karst features with clay dominated fill separate the hydrogeology of the area into a number of limestone blocks that form distinct groundwater bodies (GWB), refer to **Section 3.4.3** of the report, **Figure 3.11**. The full extents of the groundwater bodies are presented in **Appendix F, Figure 5.02**. These buried karst features also generate surface runoff unlike the limestone areas where all rainfall recharges to ground.

Lackagh Quarry remains dry most of the year apart from during peak rainfall events groundwater ponds on the lowest bench of the quarry. Groundwater level data has been recorded in the area between June 2015 and January 2017, with the highest recorded level of groundwater flooding in Lackagh Quarry being +15.7mOD, which was recorded in January 2016. Following rainfall there are a number of small seepages on the quarry faces, the majority of which are located along a clay wayboard [3](bedding plane) that separates the upper and lower quarry benches (**Figure 3.4**).

3.4.2.1 Groundwater Dependant Terrestrial Ecosystems (GWDTE)

Groundwater contributes to Coolagh Lakes, Lough Corrib, River Corrib and Galway Bay. The ecological surveys identified a number of GWDTE where the habitat is dependent on the groundwater in the groundwater bodies traversed by Lackagh Tunnel and its approaches. These include Coolagh Lakes, Ballindooley Lough and three Turloughs.

Coolagh Lakes

Coolagh Lakes comprise of an upper and lower lake that are perennial with a c.70cm seasonal fluctuation in water level. The combined area of the Coolagh Lakes ranges from 0.08km^2 (2.2km perimeter) in the summer to 0.22km^2 (3.5km perimeter) in the winter. Whilst, Upper Coolagh Lake is entirely groundwater fed, Lower Coolagh Lake is in continuity with the River Corrib.

Surface water level instrumentation was installed and monitored at Coolagh Lakes from July 2015 to January 2017 to record the seasonal water levels between the upper and lower lake as well as springs. The surface water monitoring data was supplemented with the groundwater level monitoring data from local boreholes so the interaction between surface and groundwater could be assessed. These data sources indicate that the groundwater contribution to the lake water is mainly during the autumn, winter and spring and that the groundwater input to the lakes ceases during the summer months. During the summer, the water level in the lakes lowers to the level in the River Corrib. During the winter months the lake levels rise and remains slightly higher than the River Corrib.

The upper lake receives flow from the Western Coolagh Spring and Eastern Coolagh Spring, with the Western Coolagh Spring being the main inflow (Refer **Figure 3.1** for location of springs). The flow rate from the Western Coolagh Spring has been estimated to range from 0 to 100 l/s with the flow being greatest in the winter and flow ceasing during the summer. Flow from the Eastern Coolagh Spring remains low throughout the year and with an estimated flow of <1l/s is not considered to provide a significant groundwater contribution.

Ballindooley Lough

Ballindooley Lough is a permanent lake that is located approximately 1km northeast of Lackagh Quarry and is a supporting habitat for birds listed as Special Conservation Interests (SCIs) of Lough Corrib Special Protection Area (SPA).

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[3] Clay wayboard’s are described as fossil soils (palaeosols) that developed on paleokarst surfaces during periods in which the underlying limestones were above sea level (Pracht and Sommerville, 2015).
Clay wayboard’s are present in the west of Ireland, shown most famously in the Burren Co. Clare. The Geological Survey of Ireland suggests that these thin clay layers are usually rich in volcanic ash. (gsi.ie)[4] Structural Integrity of the mosaic of Limestone pavement and Calcareous grassland is the physical and mechanical geotechnical properties that control the behaviour of the geotechnical Limestone pavement environment

During the summer period the water level in Ballindooley Lough is perched above the regional groundwater table. During the winter period the lake receives groundwater causing the lake to rise in continuity with the regional groundwater level.

Turloughs

Three Turloughs were identified in the Menlough area, with all three located outside the Lough Corrib cSAC (Refer to **Figure 3.1**). Turlough K31 lies immediately to the south of the proposed road development, Turlough K20 is located just to the north of Menlough Village and K72 is located north of Lackagh Quarry. The winter flooding of the turloughs is due to the seasonal groundwater rise. Although outside of the Lough Corrib cSAC, these turloughs are assessed in this report as there is the potential for indirect hydrogeological impacts on these features due to Lackagh Tunnel.

3.4.2.2 Limestone pavement

Limestone pavement comprises of flat bare rock surfaces with limestone blocks (clints) separated by fissures (grykes). Clints and grykes are characteristic features of Limestone pavement and these features form by a combination of chemical and physical weathering from rainfall. As rainfall is mildly corrosive to limestone, chemical weathering is enhanced over other non-calcareous rock types and where soil or vegetation is present then rainfall can become more aggressive to limestone.

Limestone pavement forms because of incident rainfall on the exposed limestone surfaces, as such Limestone pavement is dependent on rainfall. Limestone pavement characteristically forms in the unsaturated zone above the groundwater table~~.~~ Being dependant on rainfall and having a free draining unsaturated zone, Limestone pavement is not a groundwater dependent habitat.

The pathway of rainfall through the unsaturated zone to the groundwater table, follows fractures and bedding planes through the limestone bedrock. On the surface, the grykes in the Limestone pavement are fractures in the limestone that has been solutionally enlarged and they provide a rapid free draining vertical flow path that allows rainfall to drain through the bedrock and down to the groundwater table.

There are multiple areas of Limestone pavement in the region, including areas within or immediately adjacent to the proposed development boundary. As Limestone pavement occurs in the unsaturated zone, above the groundwater table and is not groundwater dependent there is no groundwater interconnectivity or dependency between the Limestone pavement within the Lough Corrib cSAC beneath which Lackagh Tunnel traverses and the other areas of Limestone pavement shown on **Figure 3.1.**

3.4.2.3 Groundwater data collection

Groundwater level data has been gathered between June 2015 and January 2017 from a number of monitoring boreholes in the area between Menlough, Lackagh Quarry and Ballindooley Lough. These include monitoring boreholes as shown in **Figure 3.10 and Table 3.1**. Based on this data the regional groundwater levels have been compiled and this allows the extents of groundwater bodies to be delineated as shown in **Figure 3.11**. The groundwater bodies are named based upon the original delineation of groundwater bodies by the GSI.

Figure 3.10: Groundwater and surface water monitoring locations along the proposed road development

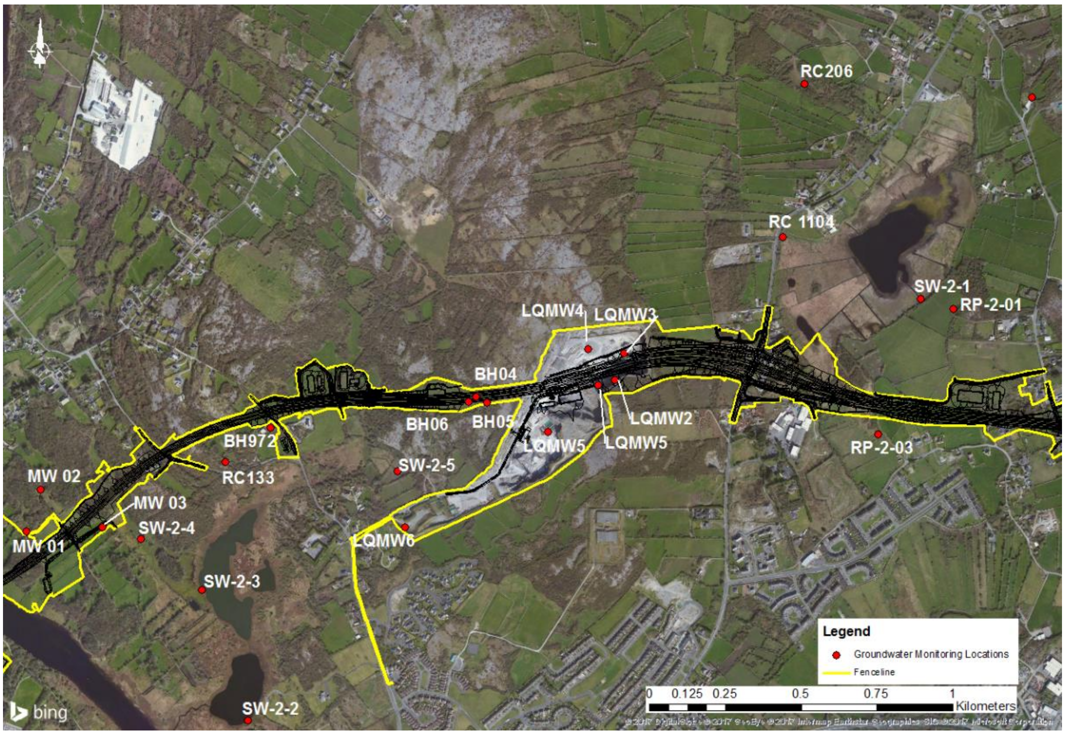
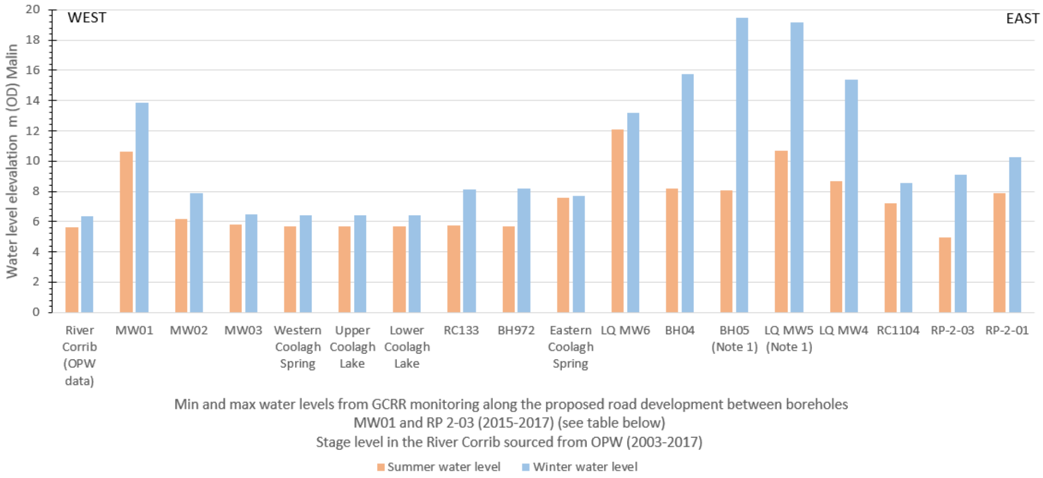


Table 3.1: Surface water and Groundwater data recorded in the GWDTE Lough Corrib Fen 1 and Clare-Corrib Groundwater Bodies (2015-2017)

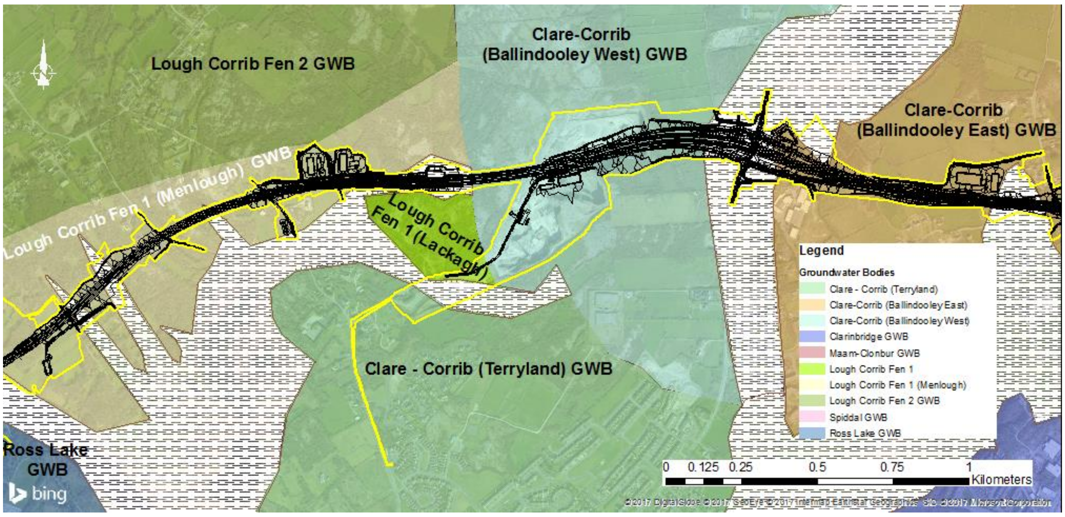


Min and max water levels from GCRR monitoring along the proposed road development between boreholes MW01 and RP 2-03 (2015-2017) (see table below)
Stage level in the River Corrib sourced from OPW (2003-2017)

Monitoring Location	Ground Elevation (mOD)	Summer GW low (mOD)	Winter GW high (mOD)	Seasonal change (m)
River Corrib (OPW data)	-	5.6	6.4	1.0
GWDTE Lough Corrib Fen 1 Groundwater Body (GWB)				
MW01	16.1	10.6	13.9	3.3
MW02	13.4	6.2	7.9	1.7
MW03	6.7	5.8	6.5	0.7
Western Coolagh Spring (SW-2-4)	5.4	5.7	6.4	0.7
Upper Coolagh Lake (SW-2-3)	-	5.7	6.4	0.7
Lower Coolagh Lake (SW-2-2)	-	5.7	6.4	0.7
RC133	11.7	5.7	8.2	2.5
BH972	12.3	5.7	8.2	2.5
Eastern Coolagh Spring (SW-2-5)	7.4	7.6	7.7	0.1
Clare-Corrib Groundwater Body (GWB)				
BH04	32.2	8.2	15.7	7.5
BH05 (Note 1)	34.1	8.1	19.5	11.4
LQ MW6	15.4	12.1	13.2	1.1
LQ MW5 (Note 1)	25.4	10.7	19.2	8.5
LQ MW4	16.8	8.7	15.4	6.7
RC1104	9.4	7.2	8.6	1.4
RP-2-03	22.4	4.9	9.1	4.2
RP-2-01	21.4	7.9	10.3	2.4

[Note 1]: Monitoring wells LQ MW5 and BH05 both straddle a thin black argillaceous limestone that overlies a clay wayboard in the geology sequence, which perches recharge above the main groundwater body. The groundwater levels recorded in BH05 and LQMW5 represent interaction between the main groundwater body and recharge. The water level data in BH05 and LQMW5 are not representative of the groundwater levels in the main groundwater body.

Figure 3.11: Groundwater bodies in the area of Lackagh Tunnel (based on 2017 data).



3.4.3 Interpretation of groundwater data

The groundwater levels shown in **Table 3.1** indicate a groundwater body divide between Lackagh Quarry and Coolagh Lakes with the watershed located near monitoring well BH04 and BH05. The divide between the Clare-Corrib GWB and the Lough Corrib Fen 1 GWB lies approximately at the boundary of Section 2 and Section 3. The tunnel sections within each GWB are as follows:

- Lackagh Tunnel Section 1 lies entirely within the Clare-Corrib GWB
- Lackagh Tunnel Section 2 lies entirely within the Clare-Corrib GWB
- Lackagh Tunnel Section 3 lies within the Lough Corrib Fen 1 GWB.

The maximum peak groundwater level recorded was +15.7mOD in BH04 during the winter of 2015/2016. Water levels in BH04 and BH05 show slightly different responses to storm events with BH05 showing short term peaks during rainfall that are higher than BH04. These short term peaks (up to +19.46mOD) are considered to be a feature of the borehole rather than the aquifer and +15.7mOD is considered to be the peak recorded groundwater level of the water table.

Peak groundwater levels in BH972 (300m west of the Section 3) were recorded in December 2015with a winter high of +8.2mOD. This data indicates a significantly lower groundwater level to the west of Section 3 at BH972 and supports the conceptual model of a groundwater divide between Clare-Corrib GWB and the Lough Corrib Fen 1 (Menlough) GWB.

On the basis of this divide, groundwater at Lackagh Quarry will drain south-eastwards towards Terryland, and not south-westwards towards Coolagh Lakes. **(Figure 3.11)** and Lackagh Quarry is in a separate groundwater catchment to Coolagh Lakes.

The limestone bedrock is classified as being a regionally important karst aquifer by the GSI based upon the high number of high yielding wells in the formation but also due to the low density of ditches and streams locally. The higher conductivities represent where test boreholes have intersected fractures and the lower conductivities represent where test boreholes encountered few or narrow discontinuities.

Based on the groundwater level data, the regional groundwater regime discharges to the Coolagh Lakes, the River Corrib, and Galway Bay. There are divides that split the groundwater into a number of bodies. In the area of Lackagh Quarry the aquifer is divided into the Lough Corrib Fen 1 (Menlough) GWB, which drains to Coolagh Lakes and the Clare-Corrib (Ballindooley West) GWB, which drains south-eastwards. Groundwater in the Clare-Corrib (Ballindooley West) GWB and Clare-Corrib (Ballindooley East) GWB likely drains through the aquifer southwards at depth towards the Terryland River sinks and from there to Galway Bay.

3.5 Existing Geological Environment

3.5.1 General

Lackagh Tunnel is located within an area of Lower Carboniferous Limestone. Rockhead level of the limestone generally exists quite close to ground level with large areas of limestone bedrock outcrops. The ground investigation demonstrated that the depth to bedrock varies from surface outcrop to 104.95m below ground level (mbgl) within the study area. Where bedrock is not exposed at ground level it is generally overlain with topsoil, glacial till (sandy gravelly CLAY) and silt deposits where rock is at depth.

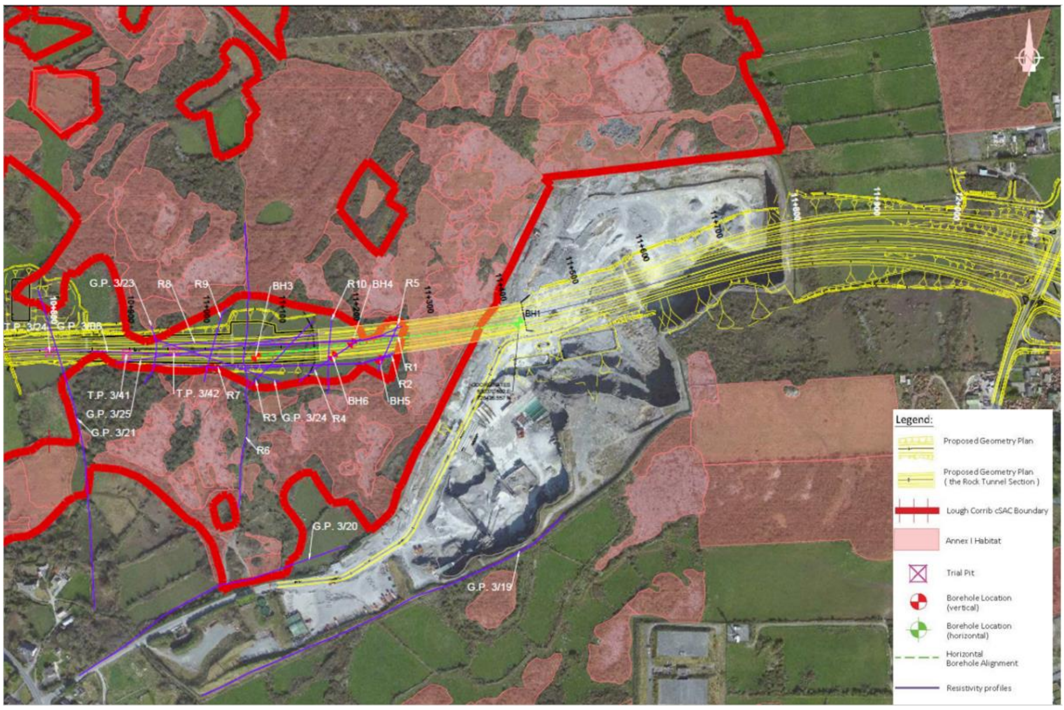
3.5.2 Site Specific Ground Investigation

A site specific ground investigation (GI) was undertaken in 2015 and 2016 to understand the ground conditions at Lackagh Tunnel comprising:

- Desk study and site walkover
- One horizontal borehole in Section 1 and Section 2
- Four vertical boreholes in Sections 2 and 3
- Geophysical Survey (surface and downhole)

A plan layout of the ground investigation is presented in **Figure 3.12**, outlining each survey location with the exception of the microgravity geophysical survey stations (118 stations across Sections 1, 2 and 3). During the ground investigation factual data was recorded and is included in **Appendix A**.

Figure 3.12: Ground investigation plan layout



In total five boreholes (BH1, 3, 4, 5 and 6), were drilled both in Lackagh Quarry and in the adjacent fields west of the quarry (Refer to **Table 3.2** and **Figure 3.12**). One horizontal rotary core borehole (BH1) (**Figure 3.13**), was drilled at an inclination of ~12° off horizontal, through the western quarry face, at the location of the proposed eastern tunnel portal and four vertical rotary core boreholes were drilled in the fields adjacent to the quarry on the west, above the proposed tunnel alignment.

Figure 3.13: BH01 Horizontal borehole at the eastern tunnel portal

Table 3.2: Summary of Lackagh Tunnel borehole data

Name	Type	End Depth / Horizontal Length	Limestone Rockhead Depth
BH01 (Sections 1 and 2)	Horizontal rotary corehole (61mm triple barrel HQ [3HQ]) along the length of the alignment for a length of 300m with an incline of 12° to the horizontal, includes rock core recovery and discontinuity logs	278m from quarry face	Immediately
BH03 (Section 3)	Vertical rotary corehole (82mm 3PQ), tricone open hole drilling from 85m	109.9mbgl (-83.6mOD)	104.95.5mbgl (-78.692mOD)
BH04 (Section 2)	Vertical rotary corehole (82mm 3PQ)	35mbgl (-2.8mOD)	4mbgl (+28.2mOD)
BH05 (Section 2)	Vertical rotary corehole (82mm 3PQ)	50mbgl (-15.9mOD)	0.4mbgl (+33.7mOD)
BH06 (Section 3)	Vertical rotary corehole (82mm 3PQ)	45mbgl (-14.2mOD)	Not encountered

Lab testing of the recovered soil samples and rock core was completed in order to attain parameters to aid in tunnel design. In-situ hydrogeological testing was also carried out in two of the four vertical boreholes.

Geophysics in the form of microgravity was carried out at Lackagh Quarry. Electrical resistivity tomography (ERT) and seismic refraction was carried out in the agricultural fields adjacent to the quarry. Details of geophysics survey are presented below in **Table 3.3** below.

Table 3.3: Summary of the Geophysical survey data

Location	Type of GI	Details	Date
Section 1, 2 and 3, along the upper bench of Lackagh Quarry and within the 3 fields immediately to the west of the quarry	Microgravity Survey	118 stations along the centre line and 15m either side of the proposed alignment and on the upper bench	27 Oct – 3 Nov 2015
ERT 1-5 located in Sections 2 and 3 in fields to west of quarry	Electrical Resistivity Tomography (ERT)	682m's of line, depth range 25-30m	27 Oct – 3 Nov 2015
ERT 6, Section 3, perpendicular to the proposed alignment (North to South)	Electrical Resistivity Tomography (ERT)	381m's of line, depth range 50-60m	25 Nov 2015
ERT 7-10, Sections 2 and 3, along and perpendicular the proposed alignment	Electrical Resistivity Tomography (ERT)	834m's of line, depth range of 25-50m	13 – 15 Jan 2015
G.P. 3/23 – G.P. 3/25, Section 3	Electrical Resistivity Tomography (ERT) and Seismic Refraction	540m's of line, depth range 25-30m	Mar – Apr 2016
G.P. 3/19, 3/20 and 3/21. East of Lackagh Quarry and west of the study area (completed as part of the hydrogeology survey)	Electrical Resistivity Tomography (ERT) and Seismic Refraction	1365m's of line, depth range 15 - 30m	Mar – Apr 2016

Downhole geophysics was also carried out in BH04 and BH05 to understand the rock mass. Geophysical logging methods undertaken comprise:

- Acoustic/Optical Televiewer surveys to identify the nature and orientation of discontinuities in the bedrock
- Fluid Temperature and Conductivity, Natural Gamma, Calliper logging in order to determine any flow pattern within the borehole and identify flow zones; identify different zones of water quality; detect the clays that contain potassium K40, and to measure the mean diameter of the borehole
- Impeller Flow meter to determine flow patterns and identify flow zones
- Focused Resistivity to aid in the identification of strata and quality of the pore water
- Full Wave Sonic, again to aid in the identification of strata

3.6 Ground Model

As discussed in **Section 3.5.2** of the report, a site specific ground investigation was undertaken which is the basis of this ground model. Several stratigraphy were encountered varying in depth along the proposed tunnel alignment.

Surface geophysics highlighted a large karst feature, possibly a doline beneath the agricultural fields adjacent to Lackagh Quarry. Overburden from this feature was recovered in BH03 and BH06. The stratigraphy encountered within Sections 1, 2 and 3 include topsoil, glacial till, silt, clay/organic clay, cobbles and boulders, weathered rock and limestone bedrock. A plan and profile of the proposed alignment and a schematic profile of Sections 1, 2 and 3 is presented in **Figure 2.1** and a geotechnical cross section is included in **Appendix B.**

Section 1 and Section 2 are appraised in a combined section as they examine the same limestone lithology and lab testing confirmed that the limestone from these sections have similar geotechnical properties. Section 3 is discussed independently as the overburden thickens and the ground conditions vary.

3.6.1 Section 1 and Section 2

Ground conditions at the western face of Lackagh Quarry comprise a cyclical sequence of carboniferous limestones (see **Figure 3.14**). Each cycle is between 10m and 15m thick and is characterised by thinly bedded, dark mud-rich (argillaceous) limestones which pass upward into thicker bedded, paler non-argillaceous limestones. The darker limestone marks the beginning of the upper bench at the western face, and is generally considered to be stronger than the paler limestones.

Figure 3.14: Cyclical sequence of Limestones at Lackagh Quarry

The stratigraphy of Section 1 and 2 was investigated by a 280m horizontal borehole (BH01) drilled sub-horizontally along at a 12° off horizontal incline along the alignment of the proposed road development, beginning at the eastern tunnel portal location. The ground conditions in Section 2 were also determined using vertical boreholes BH04 and BH05 which reached depths of 35m and 40m, respectively.

The bedrock is described as strong to very strong, thickly bedded, pale grey, fine to medium grained slightly fossiliferous limestone. Argillaceous limestones found in the quarry face were not found during investigation of Section 2, suggesting that these beds are not present moving west.

A clay wayboard of varying thicknesses from ~30cm to absent is evident on all faces of Lackagh Quarry, refer to **Figure 3.15**. A thin 20cm band of laminated mudstone, which compares favourably with the material observed on the quarry face, was encountered in BH04, however it is unknown whether this is a continuous layer or a cavity infill. BH04 and BH05 encountered several cavities, some not filled, and some infilled with clay.

Figure 3.15: Clay wayboard on the quarry face at Lackagh Quarry

Geophysical surveying included, electrical resistivity tomography (ERT) and microgravity surveying. These survey lines highlighted high resistivity limestones in the east (in Section 2) which give way to a lower resistivity zone to the west. BH06 and BH03 located within Section 3 respectively, penetrated this low resistivity zone proving thick overburden consisting of glacial tills and silts.

Both the geophysics and horizontal borehole showed the presence of karst features within the limestone rock mass in Section 2, with several cavities discovered at depth, below the proposed road alignment, as well as a large buried karst feature which underlies the agricultural fields adjacent to the quarry on the west. The boreholes cored along the proposed line of the tunnel encountered a number of cavities in the bedrock that were generally less than 0.5m in size, with some infilled cohesive material. The microgravity survey data showed a similar finding to the ERT, dense limestones in the east giving way to a less dense zone in the west. Low density readings were found at the edges of the quarry face in Section 1, resulting from historic blast damage which extends 2 to 3m into the quarry face and is further discussed below.

Rock core recovered from BH01 indicates that:

- The Limestone is laterally and stratigraphically homogenous, it is described as pale grey to grey, fine to medium grained, strong to very strong fossiliferous (slightly) weathered (slightly) to fresh massive limestone
- Historic quarry blasting has affected a zone of the quarry face extending on average 1.5 to 3.0m into the rock mass. Beyond the blast affected zone, the discontinuities become more widely spaced, and show less alteration, indicating a more stable rock mass

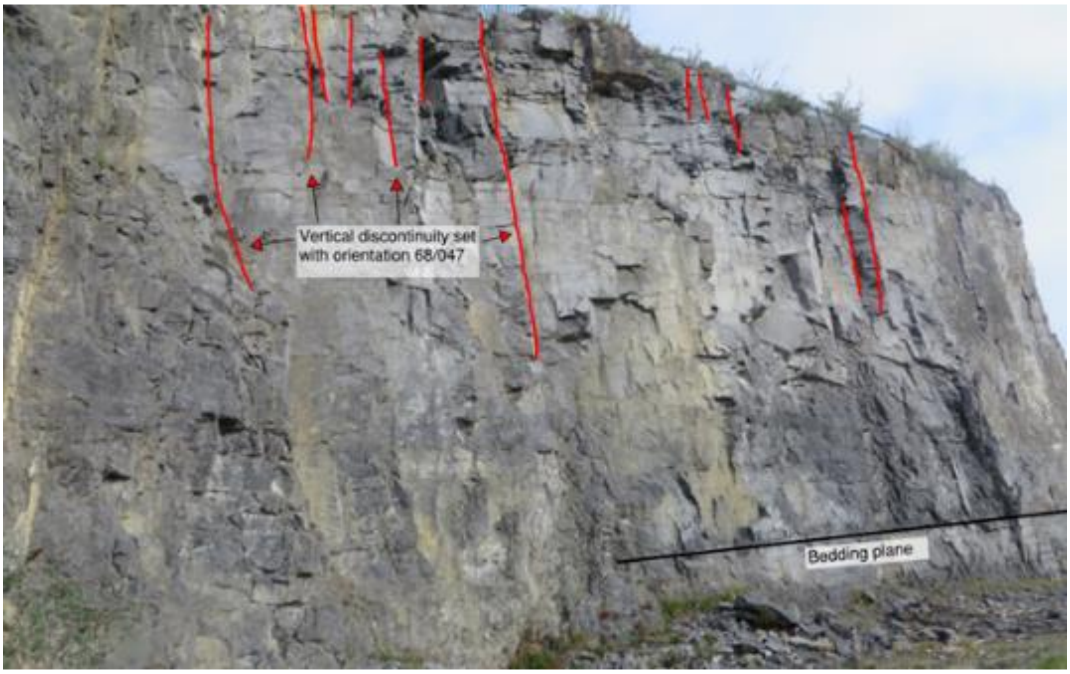
It is important to know the rock mass discontinuities, orientation and state as they can act as failure planes, impacting the Limestone pavement in Sections 1 and 2. A discontinuity is a plane of weakness in the rock mass which has a lower tensile weakness than that of the surrounding rock. It also marks a change in physical or chemical characteristics of the rock mass. Examples include bedding and jointing, both of which are evident in Lackagh Quarry. Through visual inspection, borehole logging and downhole geophysics, four discontinuity sets have been highlighted in the rock mass (**Table 3.4** and **Figure 3.16**). From these parameters an analysis of kinematic stability can be conducted.

Table 3.4: Discontinuity summary

Discontinuity Set	**Dip/Dip Direction**	**Nature of Discontinuity**
1	02/288	Bedding
2	68/047	Joint
3	54/008	Joint
4	53/204	Joint

The rock mass discontinuities provide the main flow path for groundwater. In this case the main pathway is flow along joints and bedding planes. Groundwater flow is generally from the north-west and accordingly the north-western faces of the quarry have most groundwater inflows. The main seepage zones occur where prominent bedding planes and joints intersect.

Figure 3.16: Exposed discontinuities on the upper bench



The vertical and horizontal discontinuities are visible on the exposed quarry face and are more evident in the upper bench wall, as the lower bench wall has been heavily affected by blast induced fractures.

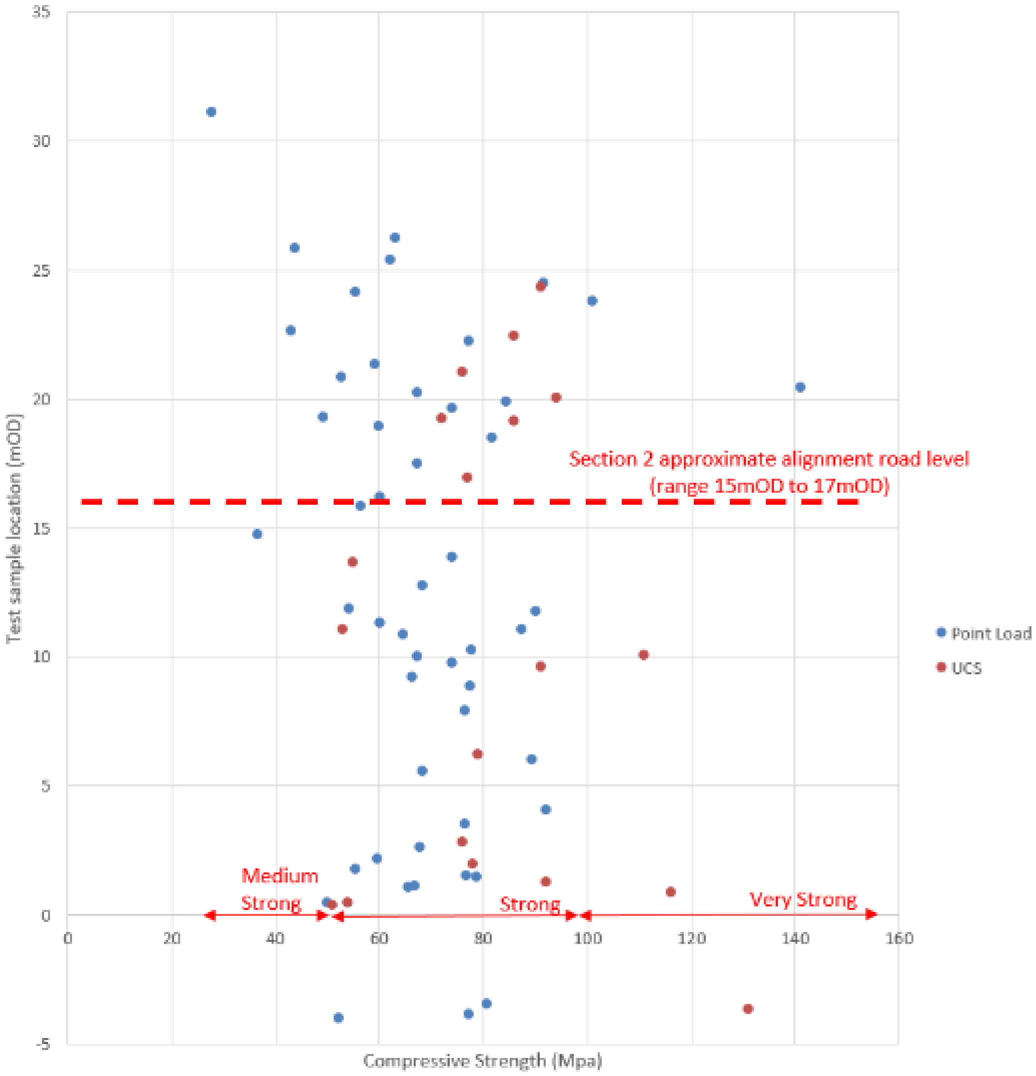
The western face has been left unprotected since the closure of the quarry in 2010 and has gradually deteriorated over time. Previous quarry workings have resulted in a heavily fractured rock face, both natural and blast induced (**Figure 3.17**), and unsafe overhangs and loose rock are present in the area of the proposed tunnel portal.

Figure 3.17: Blast damage on quarry face

Given the nature of the fracturing and the evidence of failures, the angle at which the current rock face stands is too steep in parts, suggesting that this unprotected face, if left in its present state will continue to erode and may potentially impact the overlying Limestone pavement if a deep seated slope failure was to occur.

The geotechnical laboratory test results, which consisted of Point Load testing and Uniaxial Compressive Strength (UCS) tests, from rock core samples from BH01, BH04 and BH05, confirmed that the limestone is in the strength range of strong to very strong, **Figure 3.18.**

Figure 3.18: Compressive Strength of Limestone vs Depth (mOD)



Groundwater levels in Section 1 (Lackagh Quarry Face), and Section 2 (Lackagh Tunnel) have been recorded from summer 2015 to summer of 2016. This data is presented in **Table 3.1** and shows that groundwater levels in Section 2 were recorded between 8.7m and 16.7mOD. Water filled conduits were encountered during the drilling of inclined borehole BH01. Although no conduits have been observed in Lackagh Quarry they are present within the aquifer locally.

3.6.2 Section 3

Surface geophysics and boreholes BH03 and BH06 are used to establish the ground conditions in the agricultural fields in Section 3.

The geophysical survey picked up a zone of low density, low resistivity material beneath the agricultural fields in Section 3. A large buried karst feature underlies the agricultural fields, with a stepped bedrock profile and deep overburden deposits. BH03 and BH06 confirmed the geophysics findings, bedrock was encountered in BH03 at 101.5mbgl, -75.2mOD and was not confirmed in BH06 as drilling terminated prior to hitting rock. BH03 and BH06 terminated 109.9 and 45m below ground level (-83.6 and -14.2mOD) respectively.

Overburden comprises topsoil, glacial till (boulder clay), silt, organic clay, and a transition zone consisting of cobbles and boulders which is likely to be weathered bedrock. In summary the overburden in Section 3 comprises:

- Topsoil is present throughout Section 3, although it was not recovered from the boreholes.
- Glacial Till was present in vertical boreholes BH03 and BH06 with the top surface occurring at 1.2m -1.05mbgl. Glacial Till found is described as firm to very stiff brown and grey (slightly) sandy gravelly (slightly) CLAY with occasional to some cobbles and boulders. Cobbles and Boulders are generally described as sub-rounded to sub-angular and of limestone, and occasional granites.
- Silt was found in just one borehole, BH03, which is located west of BH06. It is described as very soft to firm greenish (slightly) grey SILT. Locally its shows faint laminae. In BH03 it occurs below Glacial Till with a top surface at 13.65mbgl and a thickness of 23m.
- Clay/Organic Clay was found in both BH03 and BH06. It is generally described as soft to stiff greyish (slightly) brown to dark brown CLAY. In BH03 it is found beneath the silt stratum with a top surface at 38.38m below ground level (bgl) and a thickness of 12m. It is described as very stiff dark brown grey (slightly) organic clay towards the end of the strata with some small fibres, possible lignite. It was found again with a top surface of 61mbgl and a thickness of 10m beneath gravelly CLAY with occasional cobbles and boulders, but is described as firm to stiff locally laminated fine sandy CLAY.
- A transitional layer of gravels, cobbles and boulders, which represents the weathered rock horizon, was encountered, above slightly weathered to fresh limestone. This transition zone was encountered in both boreholes ranged in thickness from 20 to 25m. Where present it is generally described as GRAVELS, COBBLES and BOULDERS with sandy gravelly CLAY or loose, coarse gravelly COBBLES and BOULDERS with some clay. In BH03 the top surface of the cobbles and boulders was found at 80.10m BGL, with bedrock eventually being encountered at a depth of 101.5m. The stratigraphy of the weathered bedrock unit is unclear as the drilling was undertaken with a tricone bit with no recovery. In BH06 the cobbles and boulders were encountered at

22m, and have a thickness at least 20m. Its stratigraphy varies greatly over the course of the unit, as can be seen from the following generalised descriptions.

- It is described as soft to firm grey sandy clay with coarse grained angular GRAVELS and COBBLES, angular to sub-angular with occasional boulders. The clay content decreases with depth and is almost completely absent close to fresh bedrock.

In BH06, it is likely that drilling was close to the margin of a deeply buried karst rock topography and that the significant thickness of transition zone before bedrock which was encountered may represent a wall or side to the feature.

Table 3.5 below summarises the findings of BH03 and BH06 completed in Section 3 (Western Approach).

Table 3.5 Section 3 stratigraphy summary

Stratum	**Depth to top of stratum**			
	BH03		**BH06**	
	(mbgl)	**(mOD)**	**(mbgl)**	**(mOD)**
Glacial Till	1.5	+24.8	1.5	+29.3
Silt	13.7	+12.7	Not present	
Clay	38.4	-12.1	15.9	+14.9
Cobbles/Boulders (Transition)	80.1	-53.8	26.6	+4.2
Limestone bedrock	101.5	-75.2	Not reached	

Section 3 traverses the deep buried karst feature filled by fine grained sediment. The fine grained nature of the sediment indicates low hydraulic conductivity and storage and as such it is unlikely to be significantly water bearing. The bedrock surrounding the palaeokarst is water bearing and will have a water table that reduces from the groundwater high at BH04 westwards to BH972 and RC133 (refer to **Figure 3.10** for location) to the west of Section 3. On the basis of the data presented in **Table 3.1**, the groundwater level in Section 3 is estimated to range between 8.5-15.7m OD at the western tunnel portal (eastern extent of Section 3) to an estimated 6.5-10m OD at the western extent of Section 3.

4 Potential Direct and Indirect Impacts

This chapter identifies the potential direct and indirect impacts to the hydrogeological and geotechnical constraints within the zone of influence of Lackagh Tunnel and its immediate approaches. The hydrogeological assessment outlines the potential risks to groundwater bodies and flow paths for groundwater dependant terrestrial ecosystems (GWDTE) and the geotechnical assessment assesses the potential risks to Annex I habitats, Limestone pavement and Calcareous grassland within the Lough Corrib cSAC above Lackagh Tunnel during construction and operation.

For the purpose of this assessment each area is split into three areas, Section 1, 2 and 3 with a combined assessment presented in **Section 4.4** of the report.

4.1 Section 1: Lackagh Quarry Face

Section 1 is located in the now inactive Lackagh Quarry. Construction of the proposed eastern tunnel entry portal for Lackagh Tunnel will commence from the quarry. The potential construction and operation indirect and direct impacts are:

Hydrogeological:

- Changes to the groundwater recharge pattern
- Intercepting and modifying flow paths to GWDTE
- Contamination of groundwater by pollutants during construction and operation

Geotechnical:

- Rock mass instability causing destabilisation and subsequent slope failure of the quarry face and encroachment into the overlying Annex I habitats
- Rock mass instability during the construction works of Lackagh Tunnel causing destabilisation and subsequent slope failure of the quarry face and encroachment into the overlying Annex I habitats

4.2 Section 2: Lackagh Tunnel

The proposed road development tunnels beneath the Lough Corrib cSAC immediately west of Lackagh Quarry to avoid direct and indirect impacts on Limestone pavement and Calcareous grassland, both QI of the Lough Corrib cSAC at the surface. The potential construction and operation hydrogeological and geotechnical direct and indirect impacts are:

Hydrogeological:

- Modifying the groundwater divide between Lough Corrib Fen 1 (Menlough) GWB and the Clare-Corrib GWB
- Intercepting and modifying flow paths to GWDTE
- Changes to the groundwater recharge pattern

- Intercepting the groundwater table
- Contamination of groundwater by pollutants during construction and operation

Geotechnical:

- Impact the mosaic of Limestone pavement and Calcareous grassland due to collapse of the tunnel
- Impact the mosaic of Limestone pavement and Calcareous grassland due to ground settlement from the tunnel bore
- Impact to the structural integrity[4] of the Limestone pavement due to the blasting activities required for the construction of the tunnel

4.3 Section 3: Western Approach

The Western Approach traverses between the northern and southern boundary of the Lough Corrib cSAC immediately west of Lackagh Tunnel. The Western Approach cutting ranges from being predominately in rock to entirely in overburden where Section 3 encounters a buried karst feature. The potential construction and operation hydrogeological and geotechnical direct and indirect impacts are:

Hydrogeological:

- Modifying the divide between Lough Corrib Fen 1 (Menlough) GWB and Clare-Corrib GWB
- Intercepting and modifying flow paths to GWDTE
- Changes to the groundwater recharge pattern
- Intercepting the groundwater table
- Contamination of groundwater by pollutants during construction and operation

Geotechnical:

- Impact to the mosaic of Limestone pavement and Calcareous grassland due its close proximity to the proposed road development caused by significant ground settlement, rock mass and slope instability where excavated slopes are steeper than a 2 (horizontal) in 1 (vertical) to prevent encroachment on the adjacent Annex I habitats.
- Impact to the structural integrity of the Limestone pavement due to the blasting activities during the excavation of bedrock.

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[4] Structural Integrity of the mosaic of Limestone pavement and Calcareous grassland is the physical and mechanical geotechnical properties that control the behaviour of the geotechnical Limestone pavement environment

4.4 Combined Assessment

The potential hydrogeological and geotechnical direct and indirect impacts for each section have been presented independently above. These impacts are identified with respect to the constraints presented in **Chapter 3**. The combined principal potential direct and indirect impacts of Lackagh Tunnel and its immediate approaches include:

- Modifying the divide between Lough Corrib Fen 1 (Menlough) GWB and Clare-Corrib GWB
- Changes to the groundwater recharge pattern
- Intercepting the and modifying flow paths to GWDTE
- Contamination of groundwater by pollutants during construction and operation
- Encroachment onto the mosaic of Limestone pavement and Calcareous grassland due to its proximity to the proposed road development caused by rock mass instability and slope instability in Sections 1 and 3.
- Impact to the structural integrity of the Limestone pavement due to the blasting activities required for the construction of Sections 2 and 3.
- Impact the mosaic of Limestone pavement and Calcareous grassland due to collapse of the tunnel, ground settlement from the tunnel bore

5 Design, Avoidance and Mitigation

This chapter presents the design, avoidance and mitigation measures required to prevent potential direct or indirect impact to the hydrogeological and geotechnical constraints of the proposed Lackagh Tunnel based on scientific data. The design strategy, which includes the construction methodology, and mitigation measures were developed to avoid potential impacts to the hydrogeological and geotechnical constraints during construction and operation.

To ensure that the environmental management criteria outlined in this report is adopted and implemented as part of the proposed road development the environmental construction and operation requirements are included in the Schedule of Commitments.

5.1 Section 1: Lackagh Quarry Face

5.1.1 Hydrogeology Design and Avoidance

The following measures have been incorporated into the design to address the potential direct and indirect impacts to the hydrogeological constraints:

- Each drainage catchment is designed to avoid groundwater divides in order to manage road runoff and maintain recharge to the catchments of individual groundwater bodies.
- To ensure that the proposed road development is not impacted by the seasonal groundwater flooding that occurs in Lackagh Quarry, and prevent interception of the groundwater table, Section 1 invert level of Lackagh Tunnel is designed to be a minimum of 1.2m higher than the groundwater flooding recorded during the extreme winter of 2015/16
- The design of the proposed road development at the eastern portal of Lackagh Tunnel has determined the invert level of the infiltration basin. During the normal seasonal groundwater fluctuation the infiltration basin in Lackagh quarry will operate normally. However, during extreme winter events, the peak groundwater level will rise into the base of the infiltration basin. The infiltration basin is designed to function during these peak groundwater events and is designed to accommodate road runoff with a standing level of groundwater in the base of the basin.
- Discharge from the infiltration basin in Lackagh quarry retains the natural recharge pattern by maintaining recharge to the Clare-Corrib GWB.
- To ensure there is no risk of groundwater pollution during operation the drainage design for the proposed road development within Lackagh Quarry collects all surface water from the road carriageway in a sealed system which passes through hydrocarbon interceptor for pollution control before entering a treatment wetland. From the treatment wetland, the runoff is then discharged to ground via an infiltration basin. The infiltration basin will include a subsoil bed to allow the treated water to recharge to ground. The pond is designed to accommodate a 100-year storm event, with 50% of volume to infiltrate to ground within 24 hours.

5.1.2 Hydrogeology Mitigation

A hydrogeologist will be appointed, as per the Schedule of Commitments, for the construction phase by the contractor and will be present to monitor at all times when the construction activities have the potential to impact on groundwater. If karst is encountered during any excavation, e.g. excavation for an infiltration basin, it will be examined by the hydrogeologist so that the extent and pathway can be classified. The feature will then be backfilled with granular material so as to maintain the hydraulic connectivity of the pathway and it will be sealed from the excavation to avoid potential impact to the groundwater recharge pattern and flow paths to GWDTE.

Temporary bund walls are included in the design at the eastern tunnel portal as a measure to be implemented if extreme high groundwater conditions occur (>15m OD). This measure will prevent water with potentially high suspended solids that is ponded in the quarry from entering the tunnel during construction.

During the construction phase groundwater may be at risk from pollution during site storm water runoff or infiltration. To ensure this does not occur, the following construction methodology measures detailed in the Construction Environmental Management Plan (CEMP) will be implemented:

- All runoff or discharges will be treated for suspended solids before discharged.
- All liquid fuel or chemicals stored on site will be bunded within an area of sufficient capacity in order to contain 110% capacity

There are no potential direct or indirect hydrogeological impacts during the operation of Lackagh Tunnel with the implementation of the design avoidance and mitigation measures.

5.1.3 Hydrogeology Conclusion

Implementing the design, construction methodology control measures and mitigation measures will avoid potential direct and indirect impact on the existing hydrogeological environment during construction works and operation of Lackagh Tunnel.

5.1.4 Geotechnical Design and Avoidance

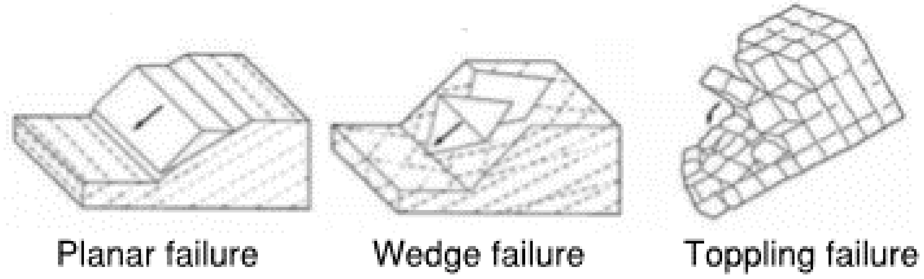
In Lackagh Quarry there is potential to impact the mosaic of Limestone pavement and Calcareous grasslands due to rock mass instability of the quarry face and during the tunnel construction works. This is assessed by determining the principal failure mechanism in Lackagh Quarry.

The three principal failure mechanisms which occur in a rock mass are discussed below and illustrated as schematics in **Figure 5.1**. The principal rock mass failure mechanisms are:

- Planar Failure
  - In order for a rock mass to undergo planar failure, the dip of the rock face must exceed the dip of the potential slip plane

  - The potential slip plane must be visible on the rock face
- Wedge Failure
  - Occurs when the dip of the rock face exceeds the dip of the line of intersection between two discontinuity planes
  - The line of intersection of the two discontinuity planes must daylight on the rock face
- Toppling Failure (Direct toppling)
  - Two sets of discontinuity planes whose intersections must dip into the rock face
  - Another set of discontinuity planes which daylight on the rock face and dip at a shallow angle

Figure 5.1: Schematic of potential failure mechanisms, Planar, Wedge and Toppling[5]



Following analysis of the site specific ground information and the discontinuity data, presented in **Table 3.4** in **Chapter 3**, it was determined that the failure most likely to occur within the rock mass and impact upon the structural integrity of the Limestone pavement is wedge failure and toppling. Wedge failures are seen in the upper section of the upper bench illustrated in **Figure 5.2** below.

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[5] G. D. Matheson, 1983, Rock Stability Assessment in Preliminary Site Investigations – Graphical Methods, TRRL Laborartory Report 1039, Transport and Road Research Laboratory, Department of the Environment Department of Transport.

Figure 5.2: Wedge failure in the upper bench

Design Support measures

In order to protect and avoid potential direct and indirect impacts to the overlying Limestone pavement/Calcareous grassland during the construction and operation works, a series of quarry face support works will be undertaken to ensure stability at the quarry face rock mass. These stability measures are required prior to and during tunnel excavation to prevent encroachment into the overlying Limestone pavement. The rock stability concern at the portal is avoided through the design of a permanent composite rock support system designed to the relevant design standards (Eurocode 7, BS8081) and best practice guidance documents. This solution will be installed prior to any excavation for the tunnel portal and remain in-situ for the design life of the tunnel. The design requires a combination of the following:

i. Rock bolts

ii. Rock dowels

iii. Steel mesh

iv. Sprayed concrete

Each of these methods are described below including the construction methodology.

Rock Bolts

There are several types of rock bolts, which generally consist of plain steel rods with a mechanical or chemical anchor at one end and a face plate and nut at the other. During the installation the rock bolt anchor (steel rod) will be inserted into a borehole that has been drilled through the rock face. The anchor is tensioned after installation and grouted. They work by 'knitting' the rock mass together sufficiently prohibiting movement to loosen and fail the rock slope. Rock bolts are effective as they are anchored into the stronger rock mass, i.e. beyond the blast affected zone, therefore >2m in length for Lackagh Quarry. Rock bolts are generally installed in patterns. The exact length, spacing and tension strength depend on the rock mass characteristics, bolt structural capacity, design standard requirements and best practice guidance documents. The rock bolts may extend in length up to 10m.

Rock Dowels

Rock dowels generally comprise deformed steel bars which are grouted into the rock. Unlike rock bolts, tensioning is not possible and the load in the dowels is generated by movements in the rock mass. In order to be effective, dowels have to be installed before significant movement in the rock mass has taken place. In the case of Lackagh Quarry Face most of the support will result from rock bolting, however the rock dowels are an added safety measure.

Like rock bolts, rock dowels are inserted into a borehole drilled into the quarry face, however they are inserted after grouting of the hole, and will be up to 3m in length. The exact length and positioning of the rock dowels depend on the rock bolt design, rock mass characteristics, dowel structural capacity, design standard requirements and best practice.

Steel Mesh

Following the installation of the rock bolts and dowels, an added safety measure of a steel mesh is proposed on the Lackagh Quarry face. This steel mesh will be put in place to cover the quarry face above the tunnel portals and 30m either side. The steel mesh will be held in place by the rock bolts. This will act as a cover on the rock face, protecting against the movement of any failures.

Sprayed concrete

An additional safety measure is using a sprayed concrete, shotcrete, coating which covers the rock bolts, dowels and steel mesh to further stabilise the quarry face. Shotcrete is usually used in conjunction with a steel reinforcement, and in this instance the steel mesh will provide sufficient support. Shotcrete is sprayed onto the rock face surface pneumatically via a shotcrete machine. Where shotcrete is utilised weep holes will be installed to allow the groundwater drain.

Design Support Solution

It is proposed that works on the upper bench wall will consist of rock bolts and rock dowels with steel mesh and shotcrete. Works on the lower bench wall will consist of rock dowels and steel mesh with shotcrete. A composite support system of rock bolts, steel mesh and sprayed concrete will be used, **Figure 5.3**. These stability measures will be installed prior to excavation works on Section 2 commencing as per the Schedule of Commitments to ensure rock mass stability and no impact to the overlying Annex I habitats.

Figure 5.3: Extent of proposed works at tunnel eastern portal

5.1.5 Geotechnical Mitigation

The potential direct and indirect impacts to the geotechnical constraints during the construction and operation of Lackagh Tunnel are predominately addressed by the design. The mitigation measures outlined below provide an added factor of safety to ensure that there is no encroachment into the overlying Annex I habitat.

During the construction of Section 1 the supported rock face and retaining walls will be monitored for movement. A geotechnical expert[6] will be appointed, as per the Schedule of Commitments, by the contractor and will be present to monitor the rock mass stability during the construction period of Section 1.

In the unlikely event that instability within the rock mass is observed additional support measures will be installed to ensure that there is no impact to the structural integrity of the surface above. The additional rock support measures comprise rock bolts, rock dowels, rock mesh, shotcrete or a combination of these measures, designed to the relevant design standards (Eurocode 7, BS8081) and best practice guidance documents. However, based on the conservative design approach and all of the support measures set out in **Section 5.1.4** it is considered that the risk of instability will be avoided and additional support measures will not be required.

During the operational phase, monitoring of the rock mass stability will continue, the exposed rock slopes in Section 1 will continue to be monitored as part of the TII (Transport Infrastructure Ireland) maintenance schedule. In the extremely unlikely event that instability within the rock mass is observed additional support measures (e.g. rock bolts, rock dowels, rock mesh, shotcrete or a combination of these measures) will be installed to enas an adsure that there is no impact to the structural integrity of the surface above. However, based on the conservative design approach, the installed composite rock support system and monitoring during

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[6] Geotechnical engineer or engineering geologist

construction it is considered that the risk of instability will be avoided and additional support measures will not be required.

5.1.6 Geotechnical Conclusion

Implementing all of the above measures will avoid potential direct and indirect impact on the structural integrity of the Annex I habitats during construction works and operation of Lackagh Tunnel.

5.2 Section 2: Lackagh Tunnel

5.2.1 Hydrogeology Design and Avoidance

The following measures are incorporated into the design to prevent potential impacts to the hydrogeological constraints:

- The hydrogeological study of the Lackagh Quarry area has identified a local perched water table and flow path along a clay wayboard in the limestone sequence. The clay wayboard will be intersected by the proposed tunnel which may generate localised inflows. These inflows are managed during construction by designing them to infiltrate to the floor of the tunnel during excavation until their inflow to the tunnel is sealed off.
- Dewatering has the potential to impact the Lough Corrib cSAC. To ensure impact does not occur the following measures detailed in the CEMP will be implemented:
    - Dewatering of the bedrock aquifer will not be permitted during construction and operation phases so there is no reduction in groundwater flow transmitted by these pathways through the aquifer to the GWDTE. This will also maintain the boundary between Clare-Corrib GWB and Lough Corrib Fen 1 (Menlough).
- All construction works will remain above the groundwater table for the duration of the works to ensure the groundwater table is not intercepted and dewatering is not required. The construction schedule will be tailored so that the excavation of the lower section will occur only during the groundwater low when the water table is below the construction level. In order to maintain the recharge pattern the tunnel will be fully lined with concrete. During operation all inflows will be transferred laterally around the tunnel via the aquifer and not be impeded from draining to the groundwater table below.

5.2.2 Hydrogeology Mitigation

A hydrogeologist will be appointed for the construction phase by the contractor and will be present to monitor at all times when the construction activities have the potential to impact on groundwater. If karst is encountered during any excavation of the proposed road development, including Lackagh Tunnel, as per the CEMP the feature will be examined by the hydrogeologist so that the extent and pathway can be assessed to advise on the granular material required to fill the feature and seal it from the excavation. By appointing a hydrogeologist and following the karst mitigation measures in the CEMP the karst feature will be sealed out from the excavation and will not be impacted by the construction.

To ensure that groundwater is not impacted by pollution during the construction phase, the following construction control measures will be implemented as detailed in the CEMP:

- A temporary barrier will be installed at the eastern portal when groundwater flooding occurs in the quarry to prevent runoff entering the tunnel from the quarry.

- All runoff or discharges will be managed as detailed in the CEMP so as to not discharge without being first treated.
- All liquid fuel or chemicals stored on site will be bunded within an area of sufficient capacity in order to contain 110% capacity.

There are no potential direct and indirect impacts during the operation of Lackagh Tunnel with the implementation of the design avoidance and mitigation measures.

5.2.3 Hydrogeology Conclusion

Implementing the design, construction methodology control measures and mitigation measures will avoid potential direct and indirect impact on the existing hydrogeological environment during construction works and operation of Lackagh Tunnel.

5.2.4 Geotechnical Design and Avoidance

Lackagh Tunnel has the potential to impact the mosaic of Limestone pavement and Calcareous grassland and the structural integrity of the Limestone pavement during tunnel construction. To prevent potential impact the size, minimum rock cover and separation of the tunnel bores are designed based upon the available geological information and the sensitivity of the habitats present above in Lough Corrib cSAC. The tunnel cross section is included in **Appendix B.**

The design requires for each individual tunnel bore to maintain at least 8m of clear rock above the crown to the top of rock/ground level. This 8m allows a stable rock arch to develop around the tunnel which will ensure the stability of the tunnel in the temporary case. The calculation showing the required depth of clear rock above the tunnel crown and the effect of the rock arch is presented in **Appendix C**. The proposed alignment for Lackagh Tunnel provides bedrock cover ranging from approximately 10m to 14.5m above the tunnel crown below the Lough Corrib cSAC which is greater than the minimum requirement of 8m.

Lackagh Tunnel comprises of two tunnel bores in close proximity to each other. The rock that separates and remains between the two tunnel bores is described as a rock pillar. If this pillar is too thin or too weak it could lead to a collapse or partial collapse of both tunnels. This pillar will see a notable stress increase as it acts as the support for the arch around both tunnels. The design demonstrates that the minimum clear distance between the tunnels should be 7m, which can be found in **Appendix D**. This was determined by analysing the quality and unconfined compressive strength of the rock encountered during the site investigation. The tunnel design allows for a rock pillar of 7.3m which is greater than the minimum requirement and will avoid potential impact to the overlying Annex I habitat.

Permanent tunnel stability will be provided by a cast in-situ reinforced concrete lining and permanent waterproofing of the tunnel will be provided by the application of a water proof membrane or equivalent.

A preliminary baseline vibration assessment was carried out with a conservative design approach vibration limit of 25mm/sec at the Limestone pavement surface and maximum instantaneous charge weights are shown in **Appendix E** to determine the structural integrity limitations of the Limestone pavement. Vibrations at this limit will not impact the structural integrity of the Limestone pavement environment. To ensure that this Limestone pavement vibration limit is not exceeded a reduced blast target limit of 20mm/sec will be implemented for Lackagh Tunnel, this target vibration limit provides a factor of safety to the construction works and is required as per the Schedule of Commitments.

Where karst features are present in the tunnel zone there is potential to impact the stability of the tunnel. If encountered these karst features will be investigated by a geotechnical expert, mapped and backfilled or bridged to ensure stability of the overlying mosaic of Limestone pavement and Calcareous grassland due to collapse of the tunnel or ground settlement from the tunnel bore.

Construction methodology

The construction methodology of the tunnel is pivotal to the design and avoidance of potential impacts to the overlying Annex I habitat. This section of the report outlines the construction methodology requirements including the construction sequence.

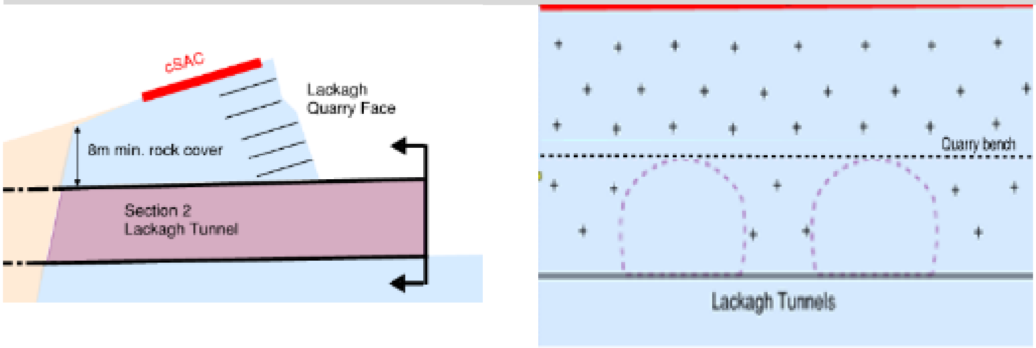
The tunnel excavation will be carried out by mined tunnel methods (drill and blast), which are commonly used for tunnels through hard rock. Prior to tunnel excavation works the following steps will be undertaken:

- A trial blast is required as per the Schedule of Commitments and will be carried out for Lackagh tunnel as part of a blast assessment. The monitored trial blast will be undertaken in the same bedrock formation by the blasting contractor in a controlled location that will pose no risk to sensitive receptors including Annex I habitat in Lough Corrib cSAC, namely Limestone pavement and Calcareous grasslands. The trial blast must not exceed the vibration limitations of the local sensitive receptors and therefore pose no impact. The trial blast will calibrate the blast design to a site specific design. The Limestone pavement vibration limitations and these site specific parameters will refine and validate the blast design properties ensuring that there will be no impact to the structural integrity of the Limestone pavement.
- The quarry face is stabilised as discussed for Section 1 (**Figure 5.4** Stage 1), then in the vicinity of the tunnel portals the lower bench will be cut back in line with the upper quarry bench (**Figure 5.4** Stage 2).

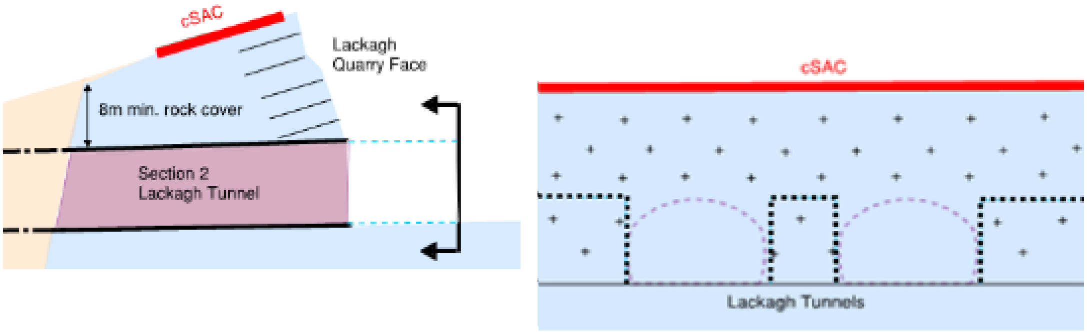
Works will be completed using drill and blast methods where rock thickness above the crown of the tunnel excavation is greater than 8m at the minimum location.

Figure 5.4: Tunnel construction sequence stage 1 and 2.

Stage 1:
Stabilise quarry face prior to tunnel excavation works using rock bolts, steel mesh and sprayed concrete



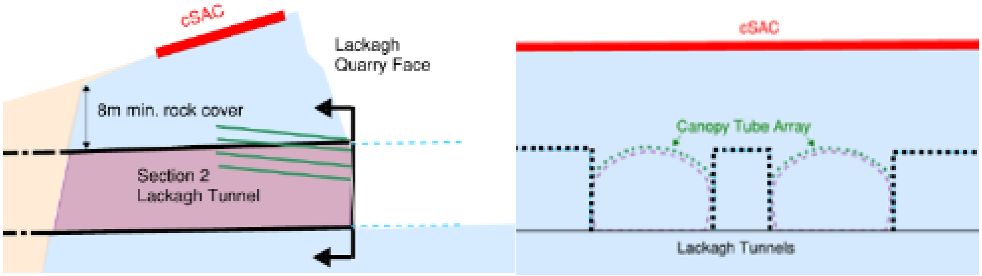
Stage 2:
Removal of quarry bench



Temporary support measures (**Figure 5.5** Stage 3) for the eastern tunnel portal will be installed around the arch of the tunnel through the quarry rock face in the form of 10-12m length sub-horizontal canopy tubes**.** Canopy tubes are steel tubes that are drilled into the ground around the tunnel arch. These tubes extend a maximum of 2m above the tunnel crown. These pre-support measures form a canopy of support and allow the portal to be excavated without causing risk of collapse to the quarry face.

Figure 5.5: Tunnel construction sequence Stage 3.

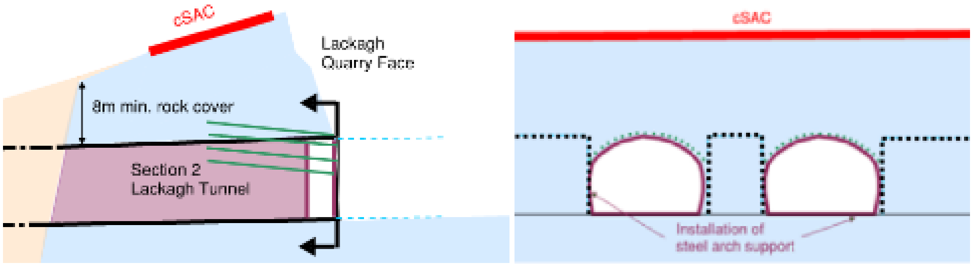
Stage 3:
Installation of tunnel pre-support (canopy tubes)



Once the temporary support measures are installed the first two metres of tunnel is excavated (Stage 4, **Figure 5.6).** A portal support structure in the form of a steel arch will then be installed to provide support to the pre-support and the ground above.

Figure 5.6: Tunnel construction sequence Stage 4.

Stage 4
First advance of tunnel



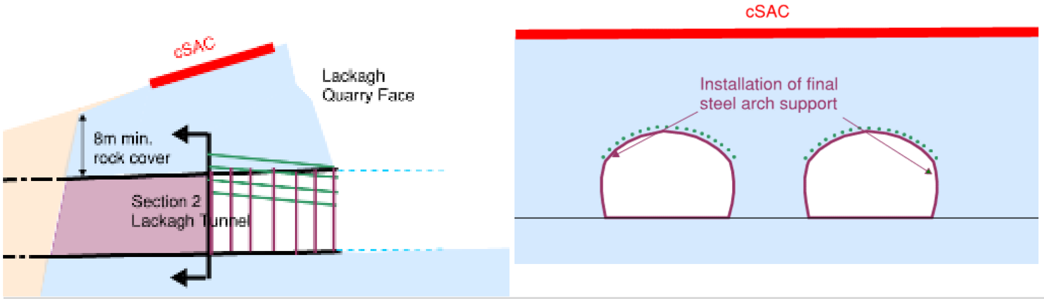
Excavation will be then progressed for the tunnel in a cyclic manner with drilling, blasting, rock face mapping by a geotechnical expert, mucking out, probing for karst features, installation of support measures and then preparing for the next advance of the tunnel (Stages 5 and 6 **Figure 5.7**). The excavation will be in short advances with steel arches and sprayed concrete implemented until the end of the pre-support zone.

Following each blast and as the tunnel advances the rock face will be mapped for discontinuities by a geotechnical expert, so that any potential instabilities are identified. Once this mapping is complete, the loose rock will be removed and any rock that was not successfully blasted will be manually broken out and temporary support measures where required will be installed. These support measures are based on the results of the mapped rock face and the presence of karst features. The most common support system is the use of radial rock bolts (discussed for Section 1) with sprayed concrete (shotcrete) which are used to develop a reinforced rock arch. These work by 'knitting' the rock mass together prohibiting movement and potential impact to the mosaic of Limestone pavement and Calcareous grassland. The maximum length of rock bolt will be 5m from the excavated tunnel face.

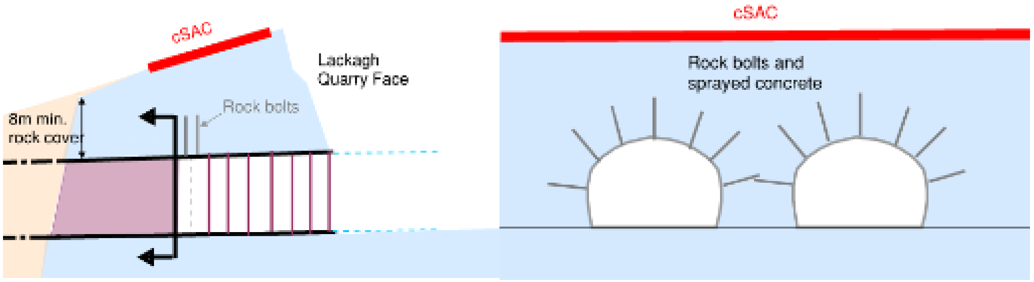
Where karst features are encountered they will be investigated, mapped and backfilled or bridged to ensure stability of the overlying mosaic of Limestone pavement and Calcareous grassland due to collapse of the tunnel or ground settlement from the tunnel bore.

Figure 5.7: Tunnel construction sequence Stage 5 and 6.

Stage 5:
Excavation until end of pre-support zone



Stage 6:
Switch to conventional drill and blast tunnelling



The blast pattern will drill, using a rock hammer, through the tunnel excavation face, the blast holes will then be loaded with detonators and explosives as per the blast design. These will be set to explode at set time intervals so that the instantaneous intensity of the blast is reduced and vibration levels are kept to below the specified vibration threshold. The blast is designed to only break out the required rock to form the tunnel.

This standard rock tunnelling methodology will cease once the rock cover is 8m based on the available ground investigation (GI) data and preliminary modelling of the tunnel. Tunnelling with less rock cover is possible and in the event that there is less than 8m cover pre-support measures in the form of sub-horizontal spiles, similar to canopy tubes, will be implemented which provide a stiffer support. Spiles will be used in addition to the rock bolts and sprayed concrete. These additional measures provide an extra level of safety to the temporary works ensuring tunnel stability during construction and no impact to the mosaic of Limestone pavement and Calcareous grassland.

To facilitate groundwater flow around the concrete lining, a drainage blanket in the form of a drainage layer or drainage pipes or similar placed outside the waterproof membrane or equivalent is installed.

Permanent tunnel support will then be installed in the form of a cast in-situ reinforced concrete lining.

5.2.5 Geotechnical Mitigation

The potential direct and indirect impacts to the geotechnical constraints during the construction and operation of Lackagh Tunnel are predominately addressed by design and avoidance. The mitigation measures outlined below provide an added factor of safety to ensure that there is no impact to the overlying mosaic of Limestone pavement and Calcareous grassland.

As set out in the Schedule of Commitments, a geotechnical expert will be appointed by the contractor and will be present to monitor the rock mass stability and blast vibrations during the Section 2 construction works.

As set out in the Schedule of Commitments, the blast target vibration limit is defined as 20% more conservative than the conservative design approach vibration limit of 25mm/sec at the Limestone pavement surface which provides an added factor of safety to the construction works to ensure that blasting will not impact the structural integrity of the Limestone pavement environment. In addition as construction mitigation the Limestone pavement blast vibrations will be monitored during the tunnelling works. In the unlikely event that the blast target vibration limit at the surface is exceeded blasting works will cease on site until it is understood the basis for the increased vibration. The blast design will then be recalibrated and blasting works will proceed with continued monitoring.

Minimal settlement or deformation, less than 10mm, of the tunnel lining, is expected directly above the tunnel crown and less than 3mm settlement occurring at the surface based on the conservative design approach, refer to **Appendix C**. Any slight movement that does occur will not impact to the mosaic of Limestone pavement and Calcareous grassland.

5.2.6 Geotechnical Conclusion

The tunnel enabling works and the control measures incorporated during construction of Section 2 including stabilization of the quarry rock face, blast assessment including a trial blast, blast vibration limits, installation of the pre-tunnelling support measures, rock face mapping by a geotechnical expert following blasting and probing for karst features will ensure there will be no impact to the structural integrity of the surface above.

Implementing the design, construction methodology control measures and mitigation will avoid potential direct and indirect impact on the structural integrity of the surface above and in turn on the Annex I habitats namely Limestone pavement and Calcareous grasslands during construction works and operation of Lackagh Tunnel.

5.3 Section 3: Western Approach

5.3.1 Hydrogeology Design and Avoidance

The following measures are incorporated into the design to prevent potential impact to the hydrogeological constraints:

- Each drainage catchment is designed to avoid groundwater divides in order to manage road runoff and maintain recharge to the catchments of individual groundwater bodies.so as to not discharge without being first treated.
- Dewatering has the potential to impact the Lough Corrib cSAC. To ensure this does not occur the following construction methodology measures detailed in the CEMP will be implemented:
    - Dewatering of the bedrock aquifer will not be permitted during construction and operation phases so there is no reduction in groundwater flow transmitted by these pathways through the aquifer to the GWDTE. This will also maintain the boundary between Clare-Corrib GWB and Lough Corrib Fen 1 (Menlough).
    - All construction works will remain above the groundwater table for the duration of the works to ensure the groundwater table is not intercepted and dewatering is not required. The construction schedule will be tailored so that the excavation of the lower section will occur only during the groundwater low when the water table is below the construction level.
- A watertight seal will be installed on the underside of the road base and the cutting sides to protect against groundwater inflow and prevent contamination of groundwater
- The retaining walls will be watertight to a level of +17.7mOD, which is derived from the groundwater high (+15.7mOD) plus 2m free board. This will seal out any groundwater in the subsoil or bedrock and will prevent contamination of groundwater.

5.3.2 Hydrogeology Mitigation

- A hydrogeologist will be appointed for the construction phase by the contractor and will be present to monitor at all timesso as to not discharge without being first treated.
- All liquid fuel or chemicals stored on site will be bunded within in an area of sufficient capacity in order to contain 110% capacity.

There are no potential direct and indirect impacts during the operation of Lackagh Tunnel with the implementation of the design avoidance and mitigation measures

5.3.3 Hydrogeology Conclusion

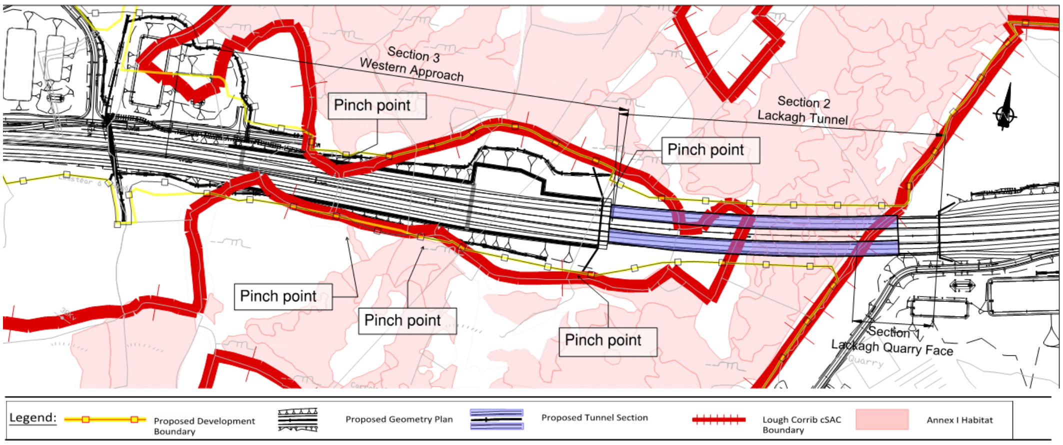
Implementing the design, construction methodology control measures and mitigation measures will avoid potential direct and indirect impact on the existing hydrogeological environment during construction works and operation of Lackagh Tunnel.

5.3.4 Geotechnical Design and Avoidance

Section 3 comprises of the Western Approach open cutting and the western tunnel entry portal. The overburden ground conditions encountered in Section 3, between existing and proposed alignment levels, would allow an unsupported 2 horizontal in 1 vertical slope. However, within Section 3 there are pinch point locations where the use of these slopes would encroach on areas of Annex I habitats. For the construction and operation of Section 3 retaining systems are designed to prevent the encroachment of the proposed road development on these areas, **Figure 5.8** and prevent potential impact to the Annex I habitat, a mosaic of Limestone pavement and Calcareous grasslands

The retaining system solution is governed by the ground conditions encountered at a particular location. As discussed in **Chapter 3** the rock head level changes significantly in Section 3. From the ground investigation data, the ground conditions at the pinch point locations where retaining systems are required vary from overburden only, rock only and a combination of overburden and rock ground conditions.

Figure 5.8: Plan Section outlining slope pinch points



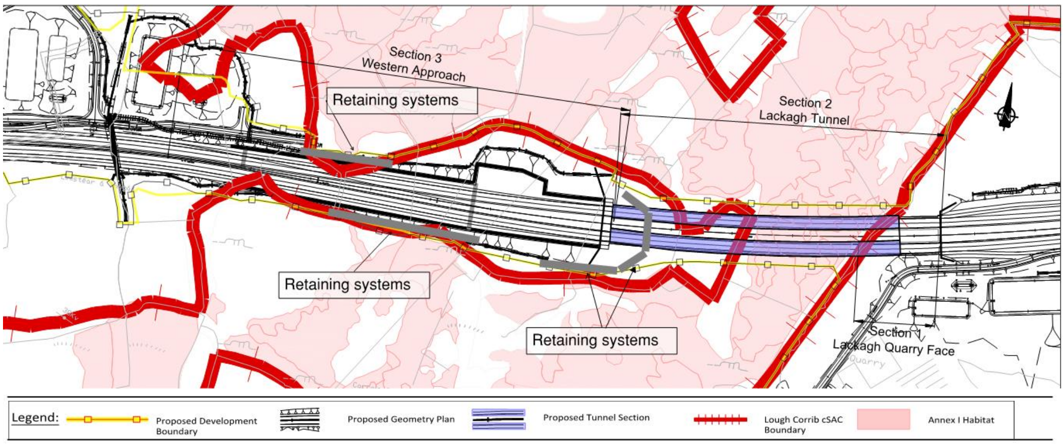
Slope retaining systems

Retaining systems are required and will be installed in Section 3 at the locations shown in **Figure 5.9** to prevent instability and potential impact on the Annex I habitat. These systems include:

1. Rock bolts, rock dowels, steel mesh, and sprayed concrete (described in **Section 5.1.4** of the report) in areas of rock only
2. Piled retaining walls, supported with ground anchors in areas of overburden only and in areas with a combination of overburden and rock

Other support options include reinforced concrete retaining walls or gabion baskets filled with stone. It is also possible for a combination solution to be employed where one method is used to support the overburden such as gabion baskets and rock bolts/ rock dowels/ steel mesh / sprayed concrete are employed to support the exposed rock face. A combination solution will be implemented where shallow overburden is present which is located on the western extent of Section 3. The permanent stability solution for rock only or overburden and rock ground conditions designed to the relevant design standards (Eurocode 7) and best practice guidance documents avoid potential impact to the mosaic of Limestone pavement and Calcareous grassland that is in close proximity to the proposed road development.

Figure 5.9: Plan Section illustrating the retained locations

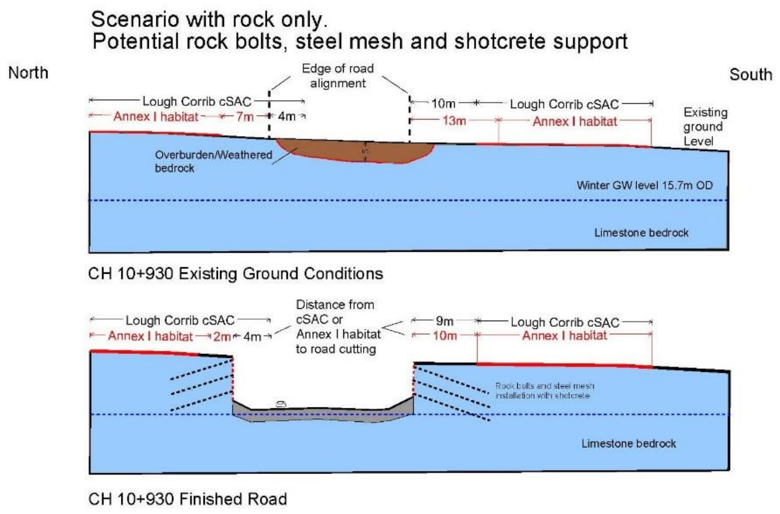


Rock retained slopes

Where rock only is present for the depth of the excavation, rock face stability composite control systems will be implemented where required to prevent potential impact to Annex I habitat. This will include rock bolts, rock dowels, steel mesh and sprayed concrete as discussed in **Section 5.1** of the report.

Rock will be excavated predominately using drill and blasting methods during construction. Rock excavation will be progressed in levels in a cyclic manner including drilling, blasting, rock mapping by a geotechnical expert and mucking out. A composite rock stability support system in the form of rock bolts, steel mesh and sprayed concrete will be implemented where required on the rock face prior to excavation to the next excavation level based on the rock mapping results. **Figure 5.10** presents a schematic of a retained design solution at a rock only pinch point in Section 3.

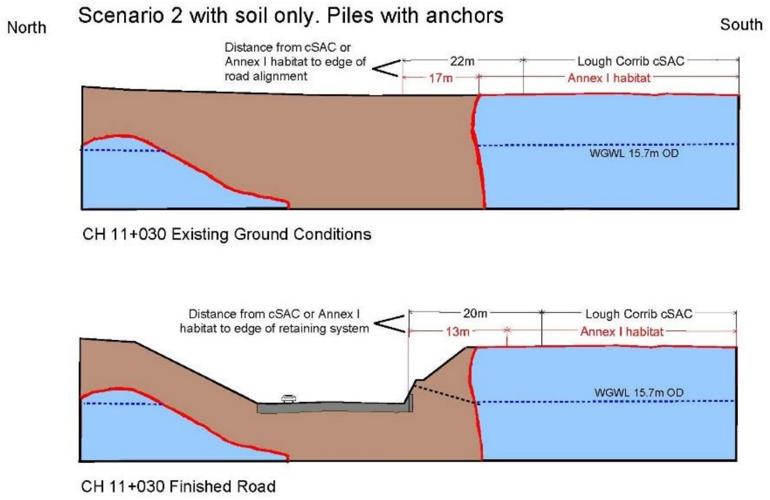
Figure 5.10: Schematic cSAC Pinch Point at CH10+930



Piled retained slopes

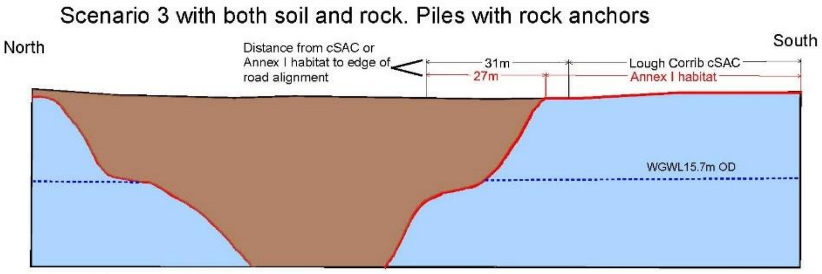
In the central area of Section 3 (Western Approach) the ground investigation indicates that overburden only is present for the depth of the road excavation. In these locations a piled retaining wall solution will be installed, **Figure 5.11.** This retaining system is installed from the existing ground level prior to excavation. The retaining structure may require permanent and/or temporary support in the form of ground anchors which are installed in the same way as rock bolts, through the retaining wall under the Limestone pavement. The installation and use of these rock bolts will not impact the structural integrity of Limestone pavement. Ground anchors limit the temporary and long term deflection of the retaining wall and control the risk of settlement of the Limestone pavement avoiding potential impact.

Figure 5.11: Schematic Lough Corrib cSAC Pinch Point at CH. 11+030

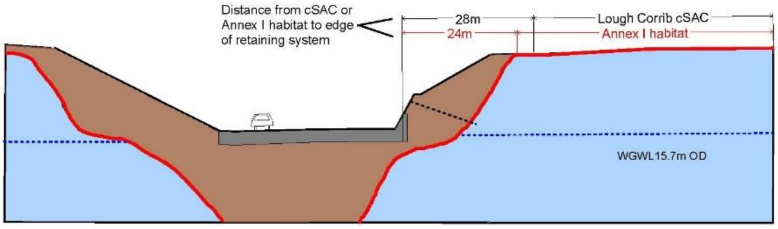


Where a combination of overburden and rock is present for the depth of the road excavation, a piled retaining wall solution will be installed, **Figure 5.12.**

Figure 5.12: Schematic Lough Corrib cSAC Pinch Point at CH. 11+140



CH 11+140 Existing Ground Conditions



CH 11+140 Finished Road

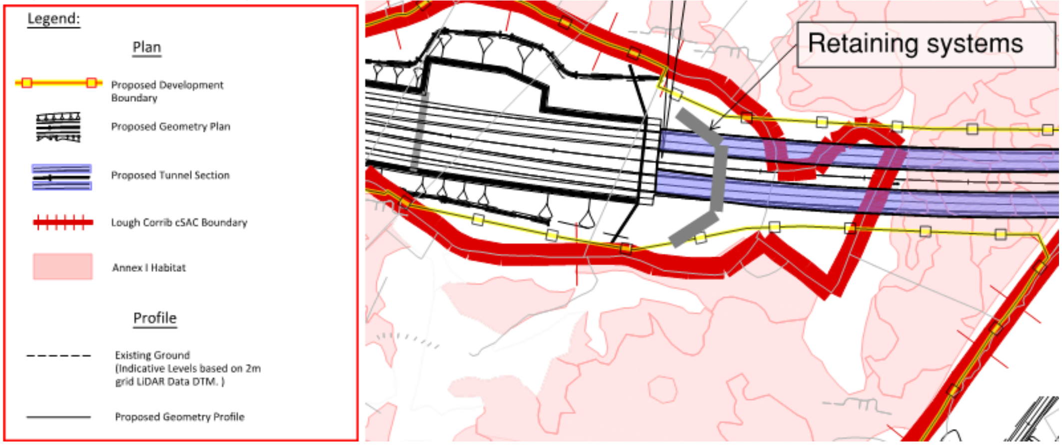
Western tunnel portal and tunnel entry structure

Lackagh Tunnel extends approximately 30m westwards, across the buried karst feature. Control measures have been designed to enable the construction and operation of the western entry portal and prevent encroaching on the Annex I habitats within Lough Corrib cSAC which are located to north, south and east of the portal. The western portal will be constructed following the excavation of the Western Approach. During the excavation slope retaining systems will be installed where an unsupported 2 horizontal in 1 vertical slope is not possible. As described for the Western Approach the retaining system solution is governed by the ground conditions encountered at a particular location. These stability systems include the following:

- In areas of overburden, retaining walls will be implemented
- In areas of rock, rock stability measures will be implemented including rock bolts, rock dowels, steel mesh and sprayed concrete.

These controls are outlined in the Schedule of Commitments and will be implemented as part of the construction methodology to enable the construction and operation of the western entry portal. These measures will prevent encroaching on the Annex I habitats within Lough Corrib cSAC

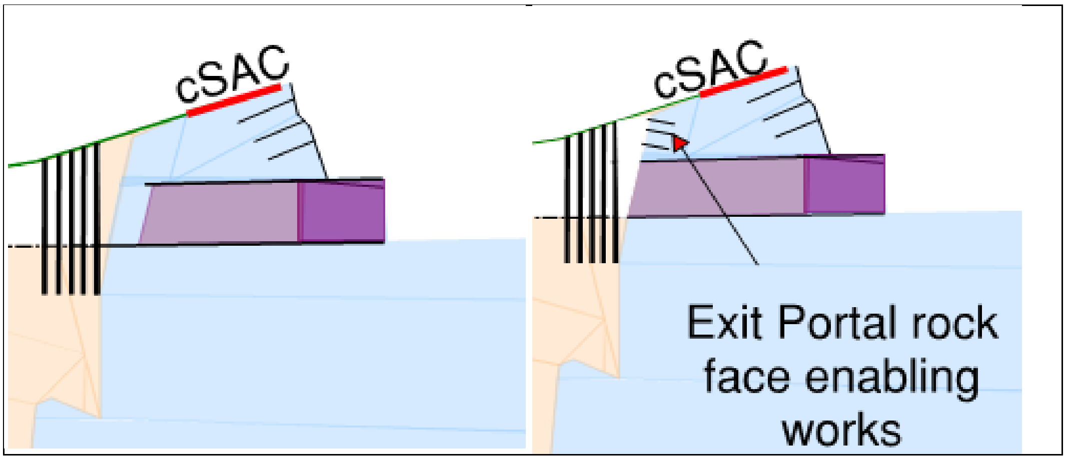
Figure 5.13: Lough Corrib cSAC Pinch Point between CH. 11+150 and CH11+180



During the excavation of Section 3 the overburden and rock face above the western tunnel entry portal will be exposed. Retaining systems will be installed during construction to prevent slope instability and encroachment on the Annex I habitats within Lough Corrib cSAC during construction and operation above the tunnel portal, refer to **Figure 5.13**

During excavation in areas of rock, the rock face will be mapped by a geotechnical expert so that any potential instabilities are identified. A rock stability system similar to Section 1 including a combination of rock bolts, rock dowels, steel mesh and sprayed concrete will be installed where required. Stability works including sub horizontal canopy tubes for the eastern tunnel entry portal and tunnelling works as described for Section 2 (**Section 5.2.4** of the report) shall be utilised if required.

Figure 5.14: Schematic of the exit portal rock face enabling works



The construction methodology requirements for Section 3 are listed below:

- As outlined for Section 2 a blast assessment including a trial blast will be carried out as per the Schedule of Commitments prior to blasting works in Section 2 or 3. The monitored trial blast will calibrate the blast design to a site specific design and ensure that there will be no impact to the structural integrity of the Limestone pavement. In the unlikely event that blasting is not viable the rock will be excavated slowly using hydraulic hammers

- Rock mapping assessments will be completed by a geotechnical expert during excavation and in stages on exposing rock following the excavation 2-4m overburden to determine the rock stability solution that will be employed avoiding impact to mosaic of Limestone pavement and Calcareous grassland that is in close proximity to the proposed road development.
- Horizontal deflections of the retaining walls will be monitored during construction and compared with the design to ensure there is no impact to mosaic of Limestone pavement and Calcareous grassland that is in close proximity to the proposed road development.

5.3.5 Geotechnical Mitigation

The potential direct and indirect impacts to the geotechnical constraints during the construction and operation of Lackagh Tunnel are predominately addressed by design and avoidance. The mitigation measures outlined below provide an added factor of safety to ensure that there is no impact to the mosaic of Limestone pavement and Calcareous grassland that is in close proximity to the proposed road development.

As set out in the Schedule of Commitments, a geotechnical expert will be appointed by the contractor and will be present to monitor the rock mass stability and blast vibrations during the Section 3 construction works.

During the construction phase, during the installation of the support measures, including rock and overburden retaining systems, Section 3 will be monitored for instability although it is considered that based on the design support measures set out above, this risk will be avoided.

In the unlikely event that instability is observed additional support measures will be installed to ensure that there is no impact to the mosaic of Limestone pavement and Calcareous grassland that is in close proximity to the proposed road development. The additional support measures comprise ground anchors, rock bolts, rock dowels, rock mesh, shotcrete or a combination of these measures, designed to the relevant design standards (Eurocode 7, BS8081) and best practice guidance documents.

During the operational phase, monitoring of the rock mass stability will continue, the rock and overburden retaining systems in Section 3 will continue to be monitored as part of the TII maintenance schedule. In the extremely unlikely event that instability within the rock mass is observed additional support measures outlined above for the construction phase will be installed to ensure that there is no impact to the mosaic of Limestone pavement and Calcareous grassland. However, based on the conservative design approach, the installed composite support system and monitoring during construction it is considered that the risk of instability will be avoided and additional support measures will not be required.

Where blasting is required the blast target vibration limit is 20% more conservative than the conservative design approach vibration limit of 25mm/sec at the Limestone pavement surface providing an added factor of safety to the construction works to ensure that blasting will not impact the structural integrity of the Limestone pavement environment. In the unlikely event that the blast target vibration limit, set out in the Schedule of Commitments, is exceeded at the Limestone pavement surface that is in close proximity to Section 3, blasting works will cease on site until it is understood the basis for the increased vibration. The blast design will then be recalibrated and blasting works will proceed with continued monitoring.

5.3.6 Geotechnical Conclusion

Implementing the design, construction methodology control measures and mitigation measures will avoid potential direct and indirect impacts on the structural integrity of the surface above which supports a mosaic of Limestone pavement and Calcareous grassland during construction and operation.

5.4 Combined Assessment

The implementation of the hydrogeological and geotechnical design, avoidance and mitigation measures for Sections 1, 2 and 3 will prevent potential hydrogeological and geotechnical direct and indirect impacts during the construction works and operation of Lackagh Tunnel and its approaches.

The hydrogeological design, avoidance and mitigation measures presented in **Sections 5.1, 5.2** and **5.3** prevent the potential direct and indirect impact to divide between Lough Corrib Fen 1 (Menlough) GWB and Clare-Corrib GWB, groundwater recharge pattern, groundwater flow paths to GWDTE and contamination of groundwater by pollutants during construction and operation.

The geotechnical design, avoidance and mitigation measures presented in **Sections 5.1, 5.2** and **5.3** prevent the potential direct and indirect impact to the mosaic of Limestone pavement and Calcareous grassland due its proximity to the proposed road development and to the structural integrity of the Limestone pavement.

As a result it can be concluded that when all sections are combined there are no direct or indirect hydrogeological and geotechnical impacts as a result of Lackagh Tunnel and its immediate approaches.

6 Summary

There are a number of QI Annex I habitats some of which are groundwater dependent within Lough Corrib cSAC which are located above or immediately adjacent to the proposed road development in the area around Lackagh Quarry in Menlough which is the subject of this report.

The proposed road development tunnels beneath the Lough Corrib cSAC from the western face of Lackagh Quarry in a westerly direction and then enters a cutting which overlaps and runs adjacent to the Lough Corrib cSAC boundary.

Construction and operation of Lackagh Tunnel and the Western Approach, as a result of the proposed road development has the potential to directly and indirectly impact these sensitive ecological habitats. This report provides a geotechnical and hydrogeological assessment based on scientific data of the potential direct and indirect impacts on the existing hydrogeological regime and the structural integrity of the surrounding rock mass which supports a mosaic of Limestone pavement and Calcareous grasslands, as a result of Lackagh Tunnel.

From the geological and hydrogeological desk study, walkovers, site surveys and investigations in the area of interest it is understood that the modern undulating landscape masks an ancient landscape of deep karst landforms and valleys up to 100m in depth but now buried by thick subsoils. The rock topography and sediment fill is an integral part of the hydrogeology of the region, which along with the Lough Corrib, River Corrib, Coolagh Lakes, Ballindooley Lough and Galway Bay allows the groundwater bodies and catchments to be delineated and flow paths identified.

The design of the proposed road development in this area has considered the hydrogeological and geological environmental constraints, identified the potential direct and indirect impacts and developed a design to prevent such impacts where possible. Where potential impacts could not be prevented or avoided mitigation measures have been included.

From the assessment, the main areas of geological and hydrogeological risks to the QI Annex I habitats have been identified and are summarised below:

- Impact on groundwater recharge from runoff on sealed drainage over the operation of the lifetime of the proposed road development
- The potential impact from operation of the proposed road development on groundwater dependent terrestrial ecosystems (GWDTE) at Coolagh Lakes, Ballindooley Lough and turloughs by interception of the groundwater table and modification of the extents of the groundwater catchment
- Modification of the groundwater divide between GWDTE Lough Corrib Fen 1 GWB and Clare-Corrib GWB
- Potential pollution of groundwater from construction and operation

- Encroachment onto the mosaic of Limestone pavement and Calcareous grassland due its proximity to the proposed road development caused by rock mass instability of Lackagh Quarry Face in Section 1.
- Impact to the structural integrity of the Limestone pavement due to the blasting activities required for the construction of Sections 2 and 3.
- Impact the mosaic of Limestone pavement and Calcareous grassland due to collapse of the tunnel, ground settlement from the tunnel bore
- Instability where the road excavation requires an excavation slope steeper than a 2 (horizontal) in 1 (vertical) in Section 3 due to the proximity of the mosaic of Limestone pavement and Calcareous grassland during construction and operation.

Measures have been incorporated into the design to facilitate the operation of Sections 1, 2 and 3 for Lackagh Tunnel. The design also includes the construction design methodology for each section taking cognisance of the potential direct and indirect impacts to the existing hydrogeological and geotechnical environment.

Any impact on recharge could potentially impact the groundwater level. A reduction in recharge caused by the proposed road development would lead to a reduction in groundwater levels which may reduce flow to GWDTE. To ensure this does not occur the design of the proposed road development captures, treats and infiltrates all runoff to the ground and there will be no net loss in recharge to the groundwater catchments and potential direct and indirect impacts from reduction in groundwater quantity are avoided. This will ensure that there is no impact on recharge to groundwater.

Interception of groundwater and the modification of groundwater bodies or catchments has the potential to reduce flow to GWDTE. The hydrogeological assessment undertaken for the proposed road development has delineated groundwater bodies and identified their divides and considered seasonal fluctuation. In doing so particular attention has been applied to the area of the catchment boundaries so that the proposed road development will not modify the extent of the groundwater body. As such, particular attention has been applied to the groundwater catchment divide to ensure that these are not modified by the proposed road development. This includes replacement of natural barriers where required so as to maintain the groundwater regime of the existing environment. This is particularly the case in the Lackagh Tunnel were the tunnel and Western Approach are sealed to prevent groundwater ingress.

To avoid potential direct and indirect impacts from pollutants the design of the proposed road development incorporates control measures including no dewatering in groundwater bodies that support GWDTE along with the implementation of the control measures detailed in the CEMP. The operational phase of the proposed road development includes treatment of road runoff with infiltration to ground via an infiltration pond or for those adjacent to the River Corrib, discharge to surface water after treatment.

The potential construction and operational direct or indirect geotechnical impacts in Section 1 (Lackagh Quarry Face), Section 2 (Lackagh Tunnel) and Section 3 (Western Approach) are prevented by design, avoidance and mitigation measures. Section 1 will be supported where required by an engineered composite support system of rock bolts, steel mesh and sprayed concrete. Tunnel excavation and construction will be supported by canopy tubes, sub horizontal spiles, a portal steel structure and rock bolts. Bridging and backfilling of karstic features identified by probing will resolve the risk due to karst. The blast charge will be designed considering the sensitive receptor limits. In the permanent and operating condition the tunnel will be supported by a cast in-situ reinforced lining. Where steepened embankments are required due to the proximity to the QI Annex I habitat a suitable retaining system will be installed depending on the ground conditions. Retaining systems in rock will include rock bolts, rock dowels, steel mesh, and sprayed concrete. In areas of overburden only and a combination of overburden and rock piled retaining walls with ground anchors are recommended.

In addition to the design, including the construction methodology, mitigation measures for construction and operation are required and have been outlined in this report and are included in the Schedule of Commitments to ensure their implementation and that there is no impact to the hydrogeological and geotechnical constraints in respect to Lackagh Tunnel and its immediate approaches. At construction stage, works will be completed as per the Schedule of Commitments and the CEMP. A hydrogeology and geotechnical expert will be appointed by the contractor and will be present to monitor at all times when the construction activities have the potential to impact on groundwater or the mosaic of Limestone pavement and Calcareous grassland. Monitoring of the exposed rock slopes and retaining walls will be carried out during construction and operation to ensure there is no impact to the mosaic of Limestone pavement and Calcareous grassland, in the extremely unlikely event that instability is observed additional support measures will be installed to ensure that there is no impact to the mosaic of Limestone pavement and Calcareous grassland. The additional support measures comprise ground anchors, rock bolts, rock dowels, rock mesh, shotcrete or a combination of these measures, designed to the relevant design standards (Eurocode 7, BS8081) and best practice guidance documents.

Implementation of the design, avoidance and mitigation measures ensure there is no impact to the hydrogeological and geotechnical constraints in respect of the Lackagh Tunnel and its immediate approaches.

7 Conclusion

The potential hydrogeological direct and indirect impacts to the groundwater dependant terrestrial Ecosystems, GWDTE, and the Annex I habitat including Limestone pavement and Calcareous grasslands from the proposed Lackagh Tunnel during construction and operation have been identified and assessed.

The specific design avoidance and mitigation measures that will be carried out during construction and operation to prevent potential direct or indirect impact to the hydrogeological and geotechnical constraints of the proposed Lackagh Tunnel are delineated and based on scientific data.

Based on all of the measures outlined in this report, it is concluded that there will be no direct or indirect impact to the groundwater bodies which support GWDTE or the structural integrity of rock mass which supports the complex of Limestone pavement and Calcareous grasslands during the construction and operation of Lackagh Tunnel and its immediate approaches.